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United Nations/European Space Agency Training Course on the Use of Remote Sensing Systems in Hydrological and Agro-meteorological Applications, held in cooperation with the Regional Centre for Services in Surveying, Mapping and Remote Sensing

(Nairobi, 12-30 October 1992)

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INTRODUCTION

A. Background and objective

1. At its thirty-seventh session, in its resolution 37/90 of 10 December 1982, the General Assembly endorsed the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) and decided that the United Nations Programme on Space Applications should organize training courses on advanced space science applications and new system developments for the benefit of Member States, particularly the developing countries.

2. The United Nations/European Space Agency (ESA) Training Course on the Use of Remote Sensing Systems in Hydrological and Agrometeorological Applications was one of the activities of the Programme on Space Applications for 1992 that were endorsed by the General Assembly in its resolution 46/45 of 9 December 1991. The training course was organized in cooperation with the Regional Centre for Services in Surveying, Mapping and Remote Sensing (RCSSMRS) and hosted by RCSSMRS at Nairobi from 12 to 30 October 1992 for the benefit of participants from the Economic Commission for Africa (ECA) and Economic and Social Commission for Western Asia (ESCWA) regions.

3. The objective of the course was to provide education and practical hands-on experience to participants on various aspects of current and future visible, infrared and microwave remote-sensing systems, including the acquisition, processing, interpretation, applications and archiving of the data generated by such systems as well as on the use of the data in hydrology and agrometeorology.

4. The present report, which covers the background, objective and organization of the course, together with a summary of the lectures presented, has been prepared for the Committee and its Scientific and Technical Subcommittee. The participants will report to the appropriate authorities in their respective countries.

B. Organization and programme

5. The participants were professionals and experts with several years of experience in agronomy, meteorology, hydrology, forestry, agrometeorology and remote sensing. The co-sponsors jointly selected 12 participants and 5 observers from the following 6 countries: Botswana, Jordan, Kenya, Nigeria, Oman and the United Republic of Tanzania. Instruction was provided by experts from Canada, France, the United Kingdom of Great Britain and Northern Ireland, the Food and Agriculture Organization of the United Nations (FAO), ESA, RCSSMRS and the United Nations (Office for Outer Space Affairs).

6. Funds allocated by the United Nations and ESA for the organization of the training course were used to defray the cost of international air travel and daily subsistence allowance for six participants from the ECA and ESCWA

regions. RCSSMRS provided the course's classroom and laboratory facilities and consumable materials.

7. Opening addresses were presented by Mr. Maurizio Fea on behalf of ESA and Mr. Adigun Ade Abiodun on behalf of the United Nations. The keynote address was presented by Mr. Harvey Croze on behalf of the United Nations Environment Programme (UNEP).

I. OVERVIEW OF THE COURSE

A. Introduction and scope of the course

8. Ecological problems throughout the world have become more acute than ever and require urgent action. General awareness of the problem has increased and it is now clear that priorities must be established, because while the problems are numerous and complex, the means of solving them are rather limited. In this context, global ecological trends are of primary importance because they potentially threaten human life. In order to ensure viable and sustainable development, it is necessary to ensure the allocation of essential capabilities, which include, inter alia, the availability of relevant information and data for decision-making, national capacity-building and science for sustainable development.

9. Remote sensing, the science of observing Earth from a distance, will provide much of the necessary information in order to decide what has to be done to protect the environment and to manage the Earth's resources in order to ensure the welfare of future generations. Naturally, satellites will be the main source of information for this. The three main groups of satellites that will play a leading role are the current optical or thermal Earth-observing satellites, and the first of a series of radar satellites, which have recently been launched.

10. Today, mankind has advanced from the deployment of the first generation of passive sensor systems aboard a variety of space platforms to the utilization of high-resolution space cameras and scanners and into microwave sensing in order to monitor the resources of the Earth on a continuing basis. The development of applications for radar data is today one of the highest priorities in the remote-sensing community. Radar brings a new dimension to environmental monitoring and surveillance by satellite, because it guarantees global data collection at predictable, regular intervals.

11. Improvements have been made not only in remote-sensing systems themselves but also in the computer hardware and software used to analyse and extract information from the data that are being acquired by these systems. As the new generation of Earth-observing satellites, particularly the radar satellites, are launched and become operational, an increasing amount and diverse type of data are becoming available. Radar satellites are providing data over frequently cloudy areas that could not be monitored in the past. The use of these microwave data along with data obtained in the visible and

infrared portions of the electromagnetic spectrum in the Geographic Information System (GIS) is becoming a powerful tool to monitor, manage and protect the natural resources and the environment of the Earth.

12. Accordingly, the objective of this training course was to provide the participants with basic knowledge through education and practical training in remote-sensing systems (visible, infrared and microwave), the applications of data generated by such systems and the processing of data for subsequent hydrological and agrometeorological applications, particularly in their respective countries. Attention was focused on fundamental principles of remote sensing, including visible, infrared and radar-imaging systems, current and future Earth observation and meteorological space systems, general principles of Synthetic Aperture Radar (SAR) data acquisition and processing, the formation and interpretation of radar images, digital analysis of satellite data, use of remote-sensing techniques in detecting those processes that are of importance in agrometeorology and hydrology, and practical applications to hydrology, agriculture, forestry and land use.

13. Radars used for remote-sensing purposes may be grouped into three different categories: altimeters, scatterometers and imaging radars. Specialized applications use altimeters to determine the altitude of an object, e.g., a satellite above ground level; their applications are usually to determine land and ocean topography. Scatterometers are used to determine wind speed over a sea surface or as data to assist in the analysis of other radar data. Imaging radar can provide picture-like representations of the observed scene and finds its applications primarily in natural resource surveys and environmental monitoring. The microwave portion of the course focused primarily on imaging radars and on the analysis and interpretation of their data.

B. Fundamentals of remote sensing

14. The development of remote-sensing applications requires a knowledge of the scientific principles underlying remote sensing, including the propagation of electromagnetic radiation through the atmosphere, the interaction of radiation with matter, the detection of radiation by the sensor systems and the generation of images in photographic or computerized form. The sensors themselves are classified as imaging or non-imaging, depending upon whether the sensor data can be converted into a map-like representation of the scene observed. Remote sensing deals primarily with imaging sensors. Sensor systems are also classified as active or passive systems depending upon whether they supply their own source of radiation, as in the case of radar, or use natural radiation, as in the case of photographic systems.

15. Airborne photographic cameras still commonly use remote-sensing systems. The advantages offered by aerial photography include geometric accuracy, stereoscopic relief information, a broad range of image scale and coverage, depending upon the flight altitude and camera focal length, a broad choice of film-filter combinations to select spectral bands, well-established procedures

for acquiring and interpreting images, a large number of experienced photo-interpreters and photogrammetrists and the flexibility of acquiring images at the desired time and place.

16. Photographic systems are sensitive to the visible portion of the electromagnetic spectrum and to portions of the ultraviolet and near infrared regions. Because shorter-wavelength radiation is scattered to a greater extent by the atmosphere, resulting in hazy images, the ultraviolet band is not commonly used for remote-sensing purposes, and blue light is often excluded in favour of near infrared radiation. Thus, the three commonly used bands in colour photography in remote sensing are the green, red and infrared bands. The selection of photographic spectral bands, through the selection of films and filters, is determined by the spectral characteristics of the objects to be studied. Colour infrared film (with filters to eliminate blue light), for example, is used to study vegetation since green leaves are highly reflective in the near infrared and that reflectance is sensitive to vegetation type and condition.

17. The information obtained from aerial or space photography is generally used to create a map or is transferred onto a map. This can be done either by tracing features from the photograph onto a transparent overlay, by visually comparing features of the photograph with corresponding features on a map and transferring information freehand or by using equipment that optically or digitally superimposes the photographic image on the map.

18. Photo-interpretation involves the identification and evaluation of features on a photograph that are considered significant for some applications. The photographic elements on which the identification and evaluation are based are the size, shape, tone and colour, texture, pattern, shadow, site and association of the various features on the photograph.

19. Visual interpretation of satellite imagery is an extension of photo-interpretation of aerial photography, differing mainly in that the large scale of the satellite imagery and the lack of stereoscopy (except in the case of some SPOT data) make features less easily recognizable. While on small-scale aerial photography, an untrained viewer can recognize many common features such as trees, rows of crops, buildings, roads and animals, these features are generally too small to be seen on satellite imagery, and few untrained viewers can reliably interpret the larger features. Information must often be deduced from seemingly abstract textures, patterns and associations. Satellite image interpretation, therefore, tends to be more theoretical and more specialized than photo-interpretation. The repetitive nature of the satellite data is often useful in interpretation since images from different seasons or years will show changes that indicate the nature of the area.

20. The information gathered by a sensor system in each of possibly many spectral bands can be converted digitally into an image form. The image can then be represented in black and white with varying grey tones or in colour with varying colour hues. For each band the intensity of tone or hue is proportional to the amount of radiation that was reflected, emitted or back-

scattered by an object (target) on the surface being observed. When the primary colours (blue, green or red) are assigned arbitrarily to each spectral band and two or three of the bands are superimposed, the resulting composite image will contain a wide range of colours where each colour is the visual effect of superimposing the primary colour hues corresponding to an object on the ground. Knowing the spectral properties of various targets (e.g., water, vegetation, soil) in the spectral bands in which the sensor systems gathered the information, the primary colour that was assigned to each band and the theory of colour, the user would be able, qualitatively, to make a first-level identification of most of the objects that appear in the image. For many applications this accuracy and level of classification is sufficient.

21. Since the tones of grey or the digital values that represent an image are a measure of the radiation received by the sensor, a user can perform either a qualitative or a quantitative radiometric analysis or perhaps both. For accurate image analysis and interpretation it is essential that the user have a thorough understanding of the physical processes involved in the creation of an image. This implies being familiar with the two basic principles of radiometry, which are: (a) the validity of the principle of superposition for wavelike phenomena; and (b) the linearity of sensor response to radiation coming in its band of operation.

22. One of the limiting factors in using remote sensing on an operational basis has been the lack of data in time periods that are most adequate for optimal discrimination of features particular to a specific application. Because of cloudy conditions, a multi-temporal approach to land use also suffers from limitations of data availability. To some extent the off-nadir viewing capability of SPOT and the combined use of its data with Landsat's Thematic Mapper (TM) data have alleviated these limitations. However, in tropical areas which have excessive cloud cover, the capability of microwave radiation to penetrate clouds and light rain showers could make radar imagery of particular value to developing countries.

23. Microwave remote sensing provides the capability for day or night observations and under clear-sky or cloudy conditions. This is possible because most microwave sensor systems provide their own source of radiation (i.e., independent of the sun) and because microwave radiation, which is in the 0.3 GHz (in terms of wavelength, between 1m and 1mm) portion of the EM spectrum, can penetrate through clouds and light rainfall.

24. Although radar systems are usually defined by the frequency interval in which they operate, they are sometimes designated by their wavelength of operation. This is done because newcomers to radar technology are usually more familiar with the concept of wavelength of the EM radiation. However, frequency is the more fundamental property of EM radiation since its frequency remains constant when it passes through media of different densities while its wavelength and velocity change. To transmit information, a carrier wave of a particular frequency can be modulated by varying the amplitude of the wave (AM modulation). An alternative way is to modulate the frequency (FM modulation); this is less subject to interference and is the one commonly used to transmit high-quality signals.

25. Microwave sensors can be classified into passive and active systems. Passive systems measure microwave radiation emitted by the ground features or by the sun and reflected by the surface. Active systems "illuminate" the area under observation and measure the strength, phase and time delay of the radiation reflected by the ground features.

26. The interaction of microwave radiation with objects on the surface of the Earth depends strongly upon the electrical properties of the objects and the surface roughness relative to the wavelength of the incident radiation. The electrical properties of matter are determined by its dielectric coefficient, which is highly sensitive to water content. An analysis of the returned signal can therefore provide information on the nature of the objects, their relative size, distribution and moisture content.

27. Radar images can be obtained from either an aircraft or a satellite. In both cases, the images are obtained by transmitting microwave pulses at an angle to the vertical and measuring the intensity and time delay of each return pulse. The first return pulse corresponds to the object whose projected distance in the direction of the sensor system is the smallest. In general this pulse corresponds to the object closest to the flight path. Because of the geometry between the incident pulse and the height of objects, the projected distance in the direction of the sensor system of the upper part of an object is smaller than the distance of its corresponding ground-point projection. This effect is known as foreshortening and makes terrain of high relief appear in the image as falling towards the radar. On the images, foreshortening causes the slopes to become extended and to appear darker. This effect can be corrected with reference to a digital terrain map.

28. The foreshortening effect can become very severe so that the top of a mountain appears to be closer to the flight path than the foot of the mountain. This effect is called layover and cannot be corrected. Other image degradations include a speckle effect, which appears as noise on the image and is related to the frequency coherence of the system, as well as several effects due to the motion of an object with respect either to the sensor system or to other objects in the field of view of the radar.

29. Because the difference in distance between objects directly beneath an aircraft or a satellite is very small, the corresponding return signals often cannot be electronically discriminated. For this reason airborne radars have been designed to scan objects at some distance to one of the sides of the aircraft and are called side-looking airborne radars (SLARs).

30. The spatial resolution attainable from a radar system is independent of the altitude of the sensor platform and increases with the length of the antenna that transmits and receives the microwave pulses. A technique known as Synthetic Aperture Radar (SAR), which applies a linear frequency modulation to a transmitted long pulse in order to simulate a train of short pulses, has been developed in order to keep satellite antennas reasonably small. The technique uses the Doppler shift of the reflected pulse due to the motion of the platform and a modified data processing to simulate a much longer

antenna. The result is a higher resolution which is only limited by the power that the antenna is capable of transmitting.

31. The microwave spectrum is subdivided into various bands, each of which is referred to by a single letter and is determined by a specific range of frequencies, as follows:

Band name	Band limits (GHz)	Band name	Band limits (GHz)
P-band	0.225-0.390	K-band	10.90-36.00
L-band	0.390-1.550	Q-band	36.00-46.00
S-band	1.550-4.200	V-band	46.00-56.00
C-band	4.200-5.750	W-band	56.00-100.0
X-band	5.750-10.90		

For airborne radar missions, which account for the bulk of the microwave data gathered world wide to date, the most used bands have been in the X-band. For the satellite radar systems of the 1990s, the predominant frequency will be the C-band.

C. Radar concepts

32. For most imaging radar systems, the geometric configuration is such that a microwave beam is radiated from the side of the platform, at an angle to the surface and perpendicular to the flight direction. The radar beam is wide in the vertical dimension and narrow in the horizontal dimension. A two-dimensional imaging plane is produced by the motion of the radar platform which periodically transmits pulses. Thus, continuous strips of the Earth's surface may be "viewed" parallel and oblique to the flight direction. The scanning concept of the imaging radar is, therefore, quite different from that used by scanners that operate in the visible and infrared regions of the EM spectrum. The latter build an image on a line-by-line basis, their viewing geometry is downward-looking and the spatial resolution of the images depends upon the angular resolution of the sensor system and platform altitude and degrades away from the nadir track.

33. Imaging radars do not depend on angular resolution; instead, their across-track resolution range is determined by measuring the time delays between the reflected signals due to the transmitted pulses. The range resolution depends upon the length of the radiated pulse which determines the distance by which two objects must be separated in order to be discriminated. This resolution increases as the radiated pulses become shorter. The azimuth along-track resolution is determined by the width of the microwave beam, which is in turn determined by the length of the antenna. The azimuth resolution increases with the length of the antenna.

34. For SAR instruments, the limiting factor for their range resolution is shortening the transmitted pulse while maintaining sufficient power to detect the reflected signal. This is accomplished by coding the transmitted pulse through a linear frequency modulation, the so-called "chirped pulse". The range components of the return signal must be processed to obtain the corresponding resolution. Azimuth-related components of the same signal must similarly be processed to obtain the along-track resolution. Thus, the acquisition of SAR imagery requires a processing system that can operate on a two-dimensional array of signal data.

Instrumentation

35. A basic imaging radar system consists of a transmitter, a receiver, an antenna designed to transmit and receive microwave energy and a data-processing and recording unit. The transmitter generates a short microwave pulse with a duration of microseconds. This signal is transmitted by the antenna. The antenna directs a narrow beam into the range direction and receives the returned portion of this pulse. The design and form of the antenna determines the beam width of the "illuminated" ground surface.

36. The receiver measures the strength of the returned portion of the transmitted signal and relates the receiving time to the transmitting time in order to determine the range distance of the reflecting object relative to the radar. The receiver converts the signal waveform from a frequency band suitable for radiation to an equivalent one that is suitable for recording. This requires a correlation process between the transmitter and the receiver. The recorder and processor units turn the raw data either into an optical record (e.g., on film) or into a digital record using high-density digital tapes (HDDTs). Further processing of the radar return signals is necessary by means of correlating signal film or HDDT data to produce radar imagery or computer-compatible tapes respectively. The latter may then be used for digital display, image manipulation and analysis.

Microwave polarization

37. An electromagnetic wave consists of coupled electric and magnetic fields which oscillate at right angles to each other in a regular wavelike manner. The polarization of a waveform describes the orientation of the electric field sector at a given point in space during one period of oscillation. In the simplest case, each field oscillates only in one plane: the wave is plane-polarized. When the electric field oscillates in a vertical (horizontal) plane, the wave is vertically (horizontally) polarized. Most imaging radars use an antenna that transmits horizontally polarized radiation. Upon incidence on a ground object, a portion of the return energy retains the same polarization as the transmitted pulse while the remainder of this energy is randomly polarized (i.e., depolarized).

38. Sophisticated radar systems can transmit horizontally and vertically polarized energy. A switching mechanism in the antenna allows it to receive both the horizontal and vertical components of the return signal.

Designations such as "HH" and "VV" stand for "horizontal transmit and horizontal receive" and "vertical transmit and vertical receive" respectively. Similarly, "HV" represents "horizontal transmit and vertical receive"; this is known as cross-polarized return. Polarization of the incident radiation is an important discriminating element since ground surfaces and other targets reflect differently each of the two components mentioned. For example, a simplified model of a vegetation canopy composed of vertically linear leaves (scatterers) would provide a strong reflected signal for vertically polarized incoming radiation but a very weak signal if the radiation were polarized horizontally. Thus, the return signal can provide information on the structure of the objects being viewed.

D. Sources of radar data for remote sensing

39. Launched in July 1991, ERS-1 is a low-orbit Earth observation satellite with several microwave sensors on board. The primary mission of ERS-1 is to increase the understanding of ocean processes, to monitor the polar regions and to contribute to the World Climatology Research Programme. However, an increasing number of land-oriented applications will soon result as the international research community gains access to the data. The primary instrument on board ERS-1 is the Active Microwave Instrument (AMI), which can provide high-resolution images (C-band), wind speed through ocean wave spectra analyses and the length and direction of ocean waves. Operating in the imaging mode, AMI covers a swath of 80 to 100 kilometres, with initially assessed resolution of 27 metres in range and 29 metres in azimuth. Assessment through October 1992 also shows high precision and replicability of the data acquired by ERS-1.

40. Operating in the wind mode, AMI covers a swath of 400-500 km over the ocean with resolution cells of 50 km and measures wind speed in the range of 4-24 m/s with an accuracy of 0.5-2 m/s. Wind speed and direction are determined by measuring the strength of the back-scattered signal of each resolution element from three directions: obliquely ahead, to the side and obliquely behind the satellite path. The intensity of the three signals provides the wind speed, and the differences between them indicate the wind direction with an accuracy of 20 degrees. In wave mode operation, AMI determines the length and direction of ocean waves in 5 x 5 km cells for segments of 200-300 km along the satellite path. Ocean wavelengths of 100-1,000 m can be measured to an accuracy of 25 per cent and their direction to an accuracy of 20 degrees.

41. In addition to AMI, ERS-1 carries a Radar Altimeter (RA) that operates at a wavelength of 2 cm. This altimeter looks vertically downward to measure average wave height and wind speed and to determine the meso-scale ocean topography. Data from this altimeter will be used to determine ice type and topography as well as the water-ice boundaries. ERS-1 also carries an Along Track Scanning Radiometer (ATSR) that operates in three bands in the thermal infrared region; these bands are centred around 3.7, 11 and 12 micrometres. ATSR looks through the atmosphere at the surface of the ocean from two

directions, downward vertically and at an incidence angle of 50 degrees. The difference between the oblique and vertical measurements provides information on atmospheric absorption while the differences between measurements at the three wavelengths are used to determine atmospheric water vapour content.

42. ERS-1 data is received by ESA's network of ground stations, which include Maspalomas, Spain; Kiruna, Sweden; Fucino, Italy; and Gatineau and Prince Albert, Canada; as well as by a number of ground stations located in the industrialized and developing countries. User requests for acquisition of ERS-1 data over a particular area of the Earth or requests for specific products of ERS-1 data already acquired are channelled through ESA's Earthnet Central Facility (EECF), located in Frascati, Italy. It is the user gateway to the ERS-1 system, and performs cataloguing, handling of user requests, payload operation planning, scheduling of data processing and dissemination, quality control of data products and sensor performance monitoring.

43. The Mission Management and Control Centre (MMCC) is at the European Space Operations Centre (ESOC) at Darmstadt, Germany. It controls the satellite and schedules the instruments, communicating with the spacecraft via the Kiruna ground station. This station is used because its northerly latitude allows it to see the satellite on 10 out of the 14 daily orbits. ESA ground stations at Kiruna, Fucino, Gatineau and Maspalomas form the main network for data acquisition and the processing and dissemination of fast-delivery products.

44. Both real-time instruments and onboard recorded data are acquired by Kiruna, with the raw data being stored on high-density digital tapes. Fast-delivery processing facilities comprise two chains devoted to the SAR (image and wave mode), and one devoted to the processing of the data from other instruments. The Fucino station is used primarily for the acquisition of SAR image data and real-time low-bit rate data over the Mediterranean Sea. The stations at Gatineau and Maspalomas are used for the acquisition of recorded low-bit rate data.

45. To date, most of the radar data collected world wide have been obtained by airborne radar systems. Even with the arrival of radar satellite systems, aerial systems will continue to provide data to meet specific use-determined acquisition parameters, particularly flight direction, viewing angle and high spatial resolution. Although the bulk of the satellite radar data that will be acquired over at least the next 10 years will be obtained in the C-band, most of the experience developed to date has been with radar operating in the X-, L- and K-bands. Airborne radar such as the C/X-SAR can also be used to investigate the use of C-band radar in monitoring the Earth.

E. Digital image processing and analysis

46. The capability to digitally process large volumes of data with uniform criteria, and often data that have been enhanced or which include new bands as a result of linear transformations of the original ones, allows the routine monitoring of large areas and the attainment of a finer discrimination between classes in the scene.

47. Satellite image data as provided to the users does not generally represent the surface of the Earth with the geometric fidelity necessary for topographic maps and does not usually fit into existing standard map projections. This is due to effects that are introduced by changes in attitude, altitude and spacecraft velocity, non-linearities in the sensor scan process, unequal sensor response, effects of the Earth's curvature and rotation and elevation of the satellite over the Earth's surface. Most of these effects (the systematic ones) can be compensated for during the preprocessing geometric and radiometric correction stage; this is done more efficiently using a digital process.

48. Digital image enhancement improves the visual presentation of the information content of the image. These techniques assist in a visual interpretation or in reducing the amount of digital data to be processed but do not create any new or additional information. Common techniques include the following: contrast enhancement, spatial filtering, linear band combinations and principal component transformation. Since in any image the full dynamic range of values that the pixels could take (typically from 0 to 255) is not utilized, the contrast of the entire image can be digitally improved. A typical range of values in an image is of the order of 80, so that the contrast can be improved visually by a factor of 3. Low-pass and high-pass filters are used to smooth out the local variations of radiance values or to enhance reflectance differences, particularly at borders between two classes of objects. Principal component transformations are a way of reducing the number of data of a set of images while retaining the most significant information. Linear band combinations include generating a new band from the ratio of two bands or the ratio of the difference of two bands to the sum of the same bands; these transformations, and many others that might be performed, enhance features of interest to the interpreter.

49. The final output of the evaluation of remote-sensing data is a thematic image (or map) of the scene analysed depending upon the specific interest of the interpreter. The process of achieving this through digital processing is called "classification". Two different approaches to digital image classification have been developed: supervised and unsupervised classification. The first approach requires that the interpreter identify areas representative of the classes to be included in the thematic output in order that the classification algorithm may use statistical parameters to classify each pixel in the image into one of the classes requested. Unsupervised classifiers require little interaction by the user and are based entirely on statistical methods. The rationale behind the latter approach was to make the classifications independent of the skill of the user. However, experience has shown that the quality of the supervised classification is usually better, since the experience accumulated by the user is more fully utilized.

F. Remote-sensing applications

50. Water, which used to be taken for granted and was thought of as existing in practically infinite abundance, has become one of our most precious natural resources. Hence hydrological and water management problems represent key areas of applied science in current world-wide economic and ecological conditions. Furthermore, hydrological properties are strongly interlinked with processes at the surface of the Earth and in the atmosphere, influencing environment and climate. Water shortages or excesses may have disastrous consequences. Droughts in one region may coincide with heavy rains and floods in others. Equally essential is a continuous survey of the water quality and pollution of all major water bodies.

51. Accordingly, the need to access and forecast water supplies has increased rapidly. Satellite remote-sensing technologies have been used increasingly to satisfy these urgent requirements for information. No other method is capable of providing the necessary data in near real time, in regular temporal sequences and on a regional, continental or global scale in order to measure, monitor and model the complex hydrological processes in the environment. Most elements such as rainfall, snow, run-off, evaporation, soil moisture, sediment load and discharge, pollution, temperature, etc., show characteristic temporal and areal variations.

52. Remote-sensing applications in hydrology include inventories of water resources, measurement of land cover and assessment of wetland areas. There is limited use of remote sensing in hydrologic modelling because of dissimilarity in time and space averages. Key parameters include soil moisture, evaporation, impervious areas, land cover, extent of snow cover, water equivalent of snow cover and precipitation. Various rainfall run-off models currently used for hydrologic modelling were developed before the advent of remote sensing and are based upon the use of topographic maps.

53. The difficulty in determining the soil moisture is related to the fact that most data gathered by space-borne sensors are limited to the uppermost layers of the soil. Soil moisture can be defined as the temporary storage of precipitation within a shallow layer of the Earth that is generally limited to the zone of aeration or root zone.

54. The passive microwave region (particularly around 21 cm wavelength) has been exploited the most so far. It has been established that the moisture content can be measured to a depth of about 5 cm (perhaps as much as 10 cm) with a relative accuracy of 10-15 per cent. These measurements can be made under all-weather conditions and through light to moderate vegetation cover. Soil moisture at lower levels cannot be detected directly if covered by a dry layer.

55. SAR measurements at C-band and L-band frequencies are also sensitive to the presence of water in the topsoil layer and provide sufficient spatial resolution to separate areas of uniform land use and vegetation cover for moisture mapping. Determination of volumetric soil moisture from SAR data is

complicated by additional factors, such as vegetation cover and surface roughness, which influence back-scattering. Some of these difficulties can be overcome by multi-temporal analyses, which enable the detection of temporal changes in soil moisture content as demonstrated by means of airborne C-band scatterometer measurements.

56. Soil moisture affects the thermal properties of the soil. If vegetation is present, its appearance may be used as an indication of the water available in the root zones, provided that it is the plant's growing season. Since no straightforward remote-sensing method is available for accessing soil moisture, it is necessary to combine various measuring techniques with hydrological models. Extensive research is needed with both active microwave and thermal infrared in this field.

57. The all-weather capability of imaging radar offers considerable benefits of agricultural applications because there is a strong requirement for frequent and reliably timed images. For instance, crop inventories require the collection of data at various times during the crop growing season when there are marked differences in the appearance of each type of crop. The timing requirements are more stringent for yield prediction, when crop growth needs to be monitored at specific times during the growing season.

58. Radar has therefore aroused world-wide interest, and many experimenters have used and analysed Seasat, SIR-A and SIR-B imagery. Although the potential of SAR observations has been demonstrated by such analysis, a proper evaluation of the use of SAR as a source of information in agriculture has not been possible. There are at least two reasons for this. The first is that the L-band radars used in these space-borne missions were not optimized for applications in agriculture, and the second is that no multi-temporal imagery was available. Over the past decade a number of investigations have been carried out which are intended to fill these gaps.

59. The potential for crop identification is related to the fact that crops have different growth cycles through which their back-scatter responses follow particular temporal sequences. With a single-frequency radar (especially X-band), a combination of images taken on different selected dates can produce a good crop classification. Apart from the multi-date observation capability, for most SAR systems that have single frequency, multi-polarized data appear to be promising. For vegetation, on the basis of both models and field experiments, multi-polarized data are expected to be sensitive to differences in plane morphology. In addition, for a single-frequency radar, the use of different incidence angles appears to help crop identification. The relative contribution of the vegetation to the radar back-scatter is higher at high incidence (>40"), whereas at lower incidence the underlying soil surface may make a significant contribution.

60. Besides measuring temporal variations in crop spectral properties for identification and monitoring purposes, radar may provide useful information on canopy structure and biomass. Since the radar back-scattering coefficient can be affected by the amount of water contained in the canopy of a given

structure, as well as the underlying soil moisture and soil surface roughness, to retrieve a given crop parameter from the radar measurement requires an optimum choice of radar parameters to minimize the other effects.

G. Image analysis hardware and software

61. The aim of the image analysis hardware and software presentation was to provide insight into how to choose hardware/software configurations for image analysis, emphasis being placed on aspects that may determine the final choice of system. Where necessary, the appropriate warnings were given, particularly where technical jargon and sales or media-intensive publicity promotion serve to obscure the real merits, or demerits, of particular system configurations.

62. The following hardware systems were analysed in retrospect and according to their purpose: low-cost budget systems based on the IBM PC family of personal computers; and general-purpose workstations based on Reduced Instruction Set Computer (RISC) processors and the UNIX operating system. Particular emphasis was placed upon the graphic display subsystems available for all these systems, as well as the suitability of these graphic display subsystems for image analysis. Recommendations were made regarding suitable systems configurations for image analysis applications, and guidelines were given regarding the balance of investment to be made in the display subsystem against other system components such as raw processor speed and the provision of disk storage.

63. Software systems were considered from the perspective of the software interface, general functionality and specific remote-sensing functionality. Discussion of the software interface included a historical overview of the evolution of image analysis environments, from the traditional sub-routine libraries to the modern point-and-click approach, and the use of icons and functional diagrams to define the desired operations. More than general functionality, attention was drawn to those requirements of image analysis software which are important for remote-sensing applications but which are sometimes overlooked or neglected in general-purpose image processing systems. Consideration was also given to features of software systems that may influence the choice of one particular system before another, and mention was made of some of the image analysis software available in the public domain. A small range of PC-based image analysis software packages were made available to participants for their personal use and evaluation.

H. Geographic Information Systems

64. Geographic Information System (GIS) technology has emerged as a new and powerful tool for the analysis of geographic, environmental and statistical data in the common spatial framework. The concept of GIS aiding the environmental planning process has gained considerable attention throughout the world in recent years. Conventional databases have been commonly used by environmental planners for information storage and retrieval. This

information, however, lacks a visual, spatial context. More often, environmentalist planners need information to be displayed and related in its true geographical context (e.g., a map) in order to arrive at concrete solutions. There are many instances where environmental problems, in addition, require interpretation by superimposing or overlaying more than one thematic map on the base map of the area under study. Manually, this process is very tedious and suffers from many drawbacks.

65. A computer-based system, on the other hand, is an excellent tool that is not only speedy but also relatively free from most drawbacks. GISs are computer systems designed to store, retrieve, manipulate and analyse spatially referenced or geo-coded data. A computerized GIS allows managers to perform complex analysis by "overlaying" and displaying large volumes of spatial and non-spatial data. The interfacing of remote sensing and GIS has attracted considerable attention in the past few years.

66. Technical issues such as raster-to-vector conversions have obstructed the ready use of remote sensing information with GIS in the past. However, significant breakthroughs have been made recently to remove the bottleneck in integrating remotely sensed information with GIS. The advances in GIS technology that have enhanced its value to managers are the following:

(i) New hardware and software for digitalizing and managing data and interpreting and reproducing maps, making these tools more powerful and easier to use;

(ii) Desk-top workstations, with increased data-processing speed and data storage capabilities;

(iii) Inexpensive plotters, lowering the cost and improving the quality of producing maps, charts and tables.

67. GIS can be defined as consisting of the following three basic elements:

(i) A large amount of data which have spatial or locational characteristics;

(ii) An integrated set of programmes which distinguishes the GIS from a series of unrelated individual programmes;

(iii) A common set of subcomponents which perform such operations as data storage, retrieval and display.

From the user's point of view a GIS is a relational type of database, spatially indexed in such a way that new information can either come from external sources or be created from existing information.

68. Analyses conducted with a GIS can provide decision-makers with information in a form more readily adapted to their needs. GIS maps can be easier to work with and more readily updated than standard maps. A GIS can be

used to highlight areas on maps where action is required or where data are questionable. For example, a GIS can be used to generate maps which depict the status of a resource in a given area. Furthermore, a GIS can be used to visualize alternative scenarios so that they may be easily compared. A GIS can be used to combine different types of maps and display them in a three-dimensional form, and the scale and the features highlighted can be changed quickly.

69. Whether a GIS should be used in any given situation can be determined only by weighing the costs and benefits of performing the required analysis. The benefits are determined by the degree of complexity, integration and sophistication the GIS analysis offers over manual analysis, and the value of this information to the manager in terms of enhancing resource quality, reducing environmental degradation, saving lives, preventing costly management mistakes and increasing economic revenues. Setting up a GIS project involves the consideration of many constraints: high investment costs, additional qualified human resources, and so on.

I. Characteristics of meteorological satellites and applications in early warning for food security and environmental monitoring

70. Operational meteorological satellites provide visible and infrared data useful for meteorological analysis and weather forecasting. These meteorological forecasts are of considerable importance to agricultural applications. In addition, however, there are forms of data and products of meteorological remote-sensing satellites that are of specific interest to agrometeorology, crop output assessment and drought monitoring.

71. The characteristics of both geostationary and polar orbiting satellite systems designed for meteorological observation of the Earth were introduced, in particular, those of Meteosat (in view of its importance for rainfall estimation over Africa) and the NOAA Tiros series of satellites (useful for vegetation monitoring over extensive areas). The relative advantage of high temporal resolution, as opposed to high spatial resolution, for environmental monitoring and rainfall estimation was also discussed.

72. The FAO project at RCSSMRS, which provides the remote-sensing component to the early warning system for food security in East African countries, was briefly outlined at the training course. The project concentrates, for example, on developing methods to utilize meteorological satellite data in early warning systems for food security, the training of national staff from the East Africa region who are involved in early warning, and the distribution of imagery and value-added products to national and regional organizations similarly involved. The project also investigates conventional and electronic mechanisms to communicate remote-sensing data of the type needed for early warning to cooperating users in the region.

73. Sensor characteristics in the visible and thermal infrared regions of the spectrum were presented, along with the nature of the scanner used by Meteosat. Details of the relative importance of convective systems in the total rainfall in the equatorial belt were given, and this concept was related to the cloud characteristics inferred from Meteosat observations. For example, the duration of particular threshold temperatures at the top of storm clouds is strongly related to rainfall amounts received at the Earth's surface. Meteosat is able to monitor cloud top temperatures every 30 minutes throughout both day and night, thus enabling the near continuous estimation of rainfall amounts and distribution over continental Africa from space. Details of calibration experiments currently under way in the Inter-Governmental Authority on Drought and Development (IGADD) subregion were described to underline how the precision of satellite rainfall estimates from cold-cloud-duration (CCD) information could be improved in the future.

74. Cumulative cold-cloud-duration images compiled by accumulating values of individual CCD images for each 10-day period over East Africa during recent rainy seasons were shown to indicate the usefulness of this type of information in highlighting the current drought situation in the region.

75. The characteristics of the NOAA Advanced Very High Resolution Radiometer (AVHRR) on board the satellite were discussed in relation to the spectral characteristics of vegetation reflectance at the Earth's surface, for example, how NOAA satellites sense information in the visible and near infrared portions of the spectrum. An explanation was also given as to the nature of near infrared energy which lies just outside the visible region of human vision, but is strongly reflected by healthy and vigorous green-leaf vegetation. A summary of the research in recent decades was presented, and showed that remote sensors capable of measuring the relative amounts of visible and near infrared light reflected from vegetation can be used to monitor the development of green-leaf vegetation. It was explained that the NOAA satellites contain the necessary sensing devices which enable the monitoring of vegetation behaviour on Earth from space.

76. An index of vegetation vigour, the Normalized Difference Vegetation Index (NDVI), was explained and its use was described in measuring the relative condition of vegetation and soil moisture availability at the Earth's surface from one monitoring period to another. Composite images of vegetation generated from 10 days of data, selecting the "greenest" data to minimize the effects of cloud masking of the Earth's surface, were demonstrated to the participants along with examples of operational NOAA products for early warning which are distributed every 10 days by the FAO project to users in the region.

77. Images of this type are not without limitations, and some of the more important problems were discussed with the participants. The eruption of Mount Pinatubo in the Philippines, for example, in June 1991, caused considerable amounts of volcanic dust to enter the Earth's stratosphere. This in turn caused interference in the radiation sensed by the NOAA satellites and reduced the reliability of the information used to monitor vegetation from June 1991 up to the present time.

II. EVALUATION OF THE COURSE

78. After completing the course, the participants were requested to complete a questionnaire on various organizational aspects of the course, the time allotted to each of the subjects and practical exercises as well as the applicability of the course to their current and future activities.

79. The completed questionnaires, having been analysed, reveal that participants were satisfied with the organization and planning of the course; they noted, in particular, the high quality of the presentations. Two thirds of the participants were in favour of longer periods for practical exercises in digital image analysis. Depending upon their field of expertise, some participants felt that more time should have been allocated to various applications. The majority of participants indicated that the level and content of the training course were appropriate for the specific needs of their work. They were unanimous in expressing their appreciation to the United Nations, the European Space Agency and the Regional Centre for Services in Surveying, Mapping and Remote Sensing for having organized and sponsored the course.

Annex

PROGRAMME OF THE COURSE

Date	Time	Subject	Speaker
Monday 12 October	9-10 a.m.	Registration	
	10-10.45 a.m.	Opening ceremony	United Nations/ UNDP/ESA/RCSSMRS
	11-11.45 a.m.	Keynote address: "Environmental management: devising strategies for development without damaging the Earth's Biosphere"	H. Croze (UNEP)
	11.45 a.m.- 12.30 p.m.	Overview of remote sensing	L. Isavwa (RCSSMRS)
	2-5 p.m.	Fundamentals of radiometry	J. Baraza (RCSSMRS)
Tuesday 13 October	9-10.30 a.m.	Characteristics of satellite Earth observation systems	A. Abiodun (United Nations)
	10.45 a.m.- 12.15 p.m.	Characteristics of meteorological satellite systems (geostationary and polar)	B. Henricksen (FAO)
	2-3.30 p.m.	Principles of image formation (data acquisition, digital/ analogue representation, display techniques)	J. Baraza (RCSSMRS)
	3.30-5 p.m.	Spectral, spatial and temporal image resolution	M. Fea (ESA)
Wednesday 14 October	9-10.30 a.m.	Practical exercises on images	J. Baraza (RCSSMRS)
	10.45 a.m.- 12.15 p.m.	ERS-1 mission: objective, space and ground segment, coverage of the Earth	M. Fea (ESA)
	2-3.30 p.m.	ERS-1 instruments, data acquisition and specifications	M. Fea (ESA)

Date	Time	Subject	Speaker
	3-5 p.m.	Evaluation of ERS-1 results obtained to date	M. Fea (ESA)
	5-6.30 p.m.	Visit to RCSSMRS facilities	RCSSMRS
Thursday 15 October	9-10.30 a.m.	Principles of radar imaging, processing and analysis of ERS-1 data sets	M. Fea (ESA)
	10.45 a.m.-12.15 p.m.	Practical exercises on ERS-1, specific application (oceanography)	M. Fea (ESA)
	2-5 p.m.	Practical exercises on ERS-1, specific application (forestry/geology)	M. Fea (ESA)
Friday 16 October	9-10.30 a.m.	Estimation of rainfall and run-off	M. Fea (ESA)
	10.45 a.m.-12.15 p.m.	Applications of remote sensing to agrometeorology	M. Fea (ESA)
	2-5 p.m.	Practical exercises related to the morning session	M. Fea (ESA)
Monday 19 October	9 a.m.-12.15 p.m.	Digital image formation and diagnostics	T. Alfoldi (CCRS)
	2-3.30 p.m.	Digital image formation and diagnostics	T. Alfoldi (CCRS)
	3.45-5 p.m.	Digital image pre-processing and corrections	T. Alfoldi (CCRS)
Tuesday 20 October	9 a.m.-12.15 p.m.	Principles of digital image analysis - enhancement and classification	T. Alfoldi (CCRS)
	2-5 p.m.	Practical exercises on digital images	T. Alfoldi (CCRS)
Wednesday 21 October		Image analysis and software systems	L. Hayes (University of Dundee)

Date	Time	Subject	Speaker
Thursday 22 October	9-10.30 a.m.	Introduction to radar remote sensing	T. Alfoldi (CCRS)
	10.45 a.m.-12.15 p.m.	Radar imaging geometry	T. Alfoldi (CCRS)
	2-3.30 p.m.	Radar target interaction	T. Alfoldi (CCRS)
	3.45-5 p.m.	Radar image characteristics	T. Alfoldi (CCRS)
Friday 23 October	9-10.30 a.m.	Radar applications in geology and oceanography	T. Alfoldi (CCRS)
	10.45 a.m.-12.15 p.m.	Radar applications in hydrology and agriculture	T. Alfoldi (CCRS)
	2-3.30 p.m.	Radar applications in forestry	T. Alfoldi (CCRS)
	3.45-5 p.m.	Practical exercise on radar interpretation	T. Alfoldi (CCRS)
Monday 26 October	9 a.m.-5 p.m.	Technical visit	RCSSMRS
Tuesday 27 October	9 a.m.-12.15 p.m.	Principles of Geographic Information Systems (GIS)	G. Pierre (SCOT CONSEIL)
	2-5 p.m.	General strategy for setting up a GIS project	G. Pierre (SCOT CONSEIL)
Wednesday 28 October	9-10.30 a.m.	Case study: implementation of a regional geographic server	G. Pierre (SCOT CONSEIL)
	10.45 a.m.-12.15 p.m.	Panorama of GIS products, trends	G. Pierre (SCOT CONSEIL)
	2-5 p.m.	Pre-field trip preparation	RCSSMRS
Thursday 29 October	9 a.m.-5 p.m.	Field trip	RCSSMRS
Friday 30 October	9 a.m.-5 p.m.	Post-field trip analysis	RCSSMRS
	2-4 p.m.	Closing ceremony	

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COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

REPORT ON THE SECOND UNITED NATIONS/EUROPEAN SPACE AGENCY WORKSHOP ON BASIC SPACE SCIENCE FOR DEVELOPING COUNTRIES, CO-SPONSORED BY THE EUROPEAN SPACE AGENCY AND THE PLANETARY SOCIETY, ORGANIZED IN COOPERATION WITH THE GOVERNMENTS OF COSTA RICA AND COLOMBIA AND HOSTED BY THE UNIVERSITY OF COSTA RICA, THE INTERNATIONAL CENTRE FOR PHYSICS AND THE UNIVERSITY OF THE ANDES

(San José, Costa Rica, and Santa Fe de Bogotá, Colombia, 2-13 November 1992)

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INTRODUCTION

A. Background and objectives

1. The General Assembly, at its thirty-seventh session, adopted resolution 37/90 of 10 December 1982, endorsing the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) that the United Nations Programme on Space Applications should promote the growth of indigenous nuclei and an autonomous technological base in space technology at the local level. At its thirty-fourth session, in June 1991, the Committee on the Peaceful Uses of Outer Space endorsed the United Nations Programme on Space Applications for 1992 as recommended by the Scientific and Technical Subcommittee of the Committee at its twenty-eighth session. Subsequently, the General Assembly, at its forty-sixth session, endorsed the activities of the Programme on Space Applications for 1992 (resolution 46/45).

2. The second United Nations/European Space Agency (ESA) Workshop on Basic Space Science for Developing Countries was part of the 1992 activities of the Programme on Space Applications. The Workshop was co-sponsored by the European Space Agency and The Planetary Society, organized in cooperation with the Governments of Costa Rica and Colombia, and hosted by the University of Costa Rica, San José, Costa Rica, from 2 to 7 November 1992, and the Centre for Physics (CIF) and the University of the Andes, Santa Fe de Bogotá, Colombia, from 9 to 13 November 1992.

3. The objective of the Workshop was to strengthen basic space science in developing countries by addressing the ways and mechanisms through which the following goals can be accomplished:

- To improve the awareness of scientists about current and future scientific and technical aspects of basic space science;

- To enhance scientific cooperation among developing countries;

- To explore avenues of education, training and research on space science subjects for the benefit of developing countries;

- To create on international core group of scientists to pursue the objective of the Workshop.

4. The present report, which covers the background, objectives and organization of the Workshop, as well as a summary of presentations (see annex I to the present report), observations and recommendations made at the Workshop, has been prepared for the United Nations Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Subcommittee. Participants in the Workshop will report to appropriate authorities of the Government, universities and research institutes in their respective countries.

B. Organization and programme of the Workshop

5. Invitations to participate in the Workshop were sent by the United Nations to scientific professionals with substantial experience in one or more of the following areas: (a) basic space science and development; (b) Earth science; (c) solar-terrestrial interaction; (d) solar system science; (e) space astronomy and astrophysics; and (f) education for space science. The Workshop was attended by 122 scientists from 19 countries and 3 international organizations: Argentina, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Cuba, Czechoslovakia, Germany, Guatemala, Honduras, Mexico, Peru, Sweden, Trinidad and Tobago, United Kingdom of Great Britain and Northern Ireland, United States of America, Venezuela, European Space Agency, United States National Aeronautics and Space Administration (NASA) and United Nations (Office for Outer Space Affairs).

6. Funds allocated by the United Nations and the European Space Agency for the organization of the Workshop were used to cover the cost of international air travel and daily subsistence allowance for 19 participants from 14 countries. The Governments of Costa Rica and Colombia provided the Workshop facilities and local transportation for the duration of the Workshop.

7. In San José, welcoming addresses were presented by Mr. C. Quesada, Vice-President for Research of the University of Costa Rica; Mr. O. Morales, Minister for Science and Technology of Costa Rica; and Mr. N. Jasentuliyana, Chief of the Office for Outer Space Affairs, on behalf of the United Nations.

8. In Santa Fe de Bogotá, welcoming addresses were made by Mr. A. Infante, Rector of the University of the Andes; Mr. E. Posada, Executive Director of the International Centre for Physics (CIF); Mr. N. S. de Rubio, Minister for Foreign Affairs of Colombia; and Mr. P. Lala, Deputy Chief of the Office for Outer Space Affairs, on behalf of the United Nations.

9. The scientific programme of the Workshop (see annex II to the present report) was developed by the United Nations Office for Outer Space Affairs, in collaboration with the European Space Agency and The Planetary Society. The Workshop was scheduled to have two days of plenary and working group sessions and 10 days of special sessions with presentations by invited speakers only. The Workshop sessions were held in an informal style, leaving enough time for informal discussions and a few ad hoc contributions from participants. The afternoon of Tuesday, 10 November, the afternoon of Thursday, 12 November and the morning of Friday, 13 November, were exclusively reserved for working group sessions in which participants discussed in depth the national capabilities to develop programmes and to undertake research activities in basic space science and ways to foster international collaboration in the field. The Proceedings of the Workshop will be published in an international journal of cosmic physics and/or an international journal of comparative planetology.

OBSERVATIONS AND RECOMMENDATIONS

A. Basic space science

10. In order to assist scientists in developing countries in finding the necessary support in the pursuit of basic space science, the United Nations should exert its best efforts to create awareness of the importance of basic space science for national development among decision-makers and the general public. In reconsidering the suggestions of the first United Nations/ESA Workshop on Basic Space Science for Developing Countries, held at Bangalore, India, in 1991 (see A/AC.105/489), participants confirmed the following areas of research as parts of basic space science:

(a) Astronomy and astrophysics;

(b) Solar-terrestrial interaction and its influence on terrestrial climate;

(c) Planetary and atmospheric studies;

(d) Origin of life and exobiology.

11. Participants agreed that the following techniques would be applicable for pursuing basic space science research:

(a) Ground-based optical, infrared and radio observations and radio and optical telescopes with associated equipment;

(b) Remote sensing, both from the ground and from space;

(c) *In situ* measurements from rocket, balloon and satellite platforms;

(d) All measurements from ground-inaccessible windows (e.g., X-ray and others) which could be made only through the use of instruments and telescopes in Earth orbit;

(e) Phased radar techniques.

B. Availability and dissemination of scientific information

1. Access to information

12. The United Nations should urge the major space agencies of the world to supply advanced information regarding various projects to scientists in developing countries so that those scientists may involve themselves in follow-up studies.

13. Considering the very high price of scientific journals and increases in exchange rates of hard currencies, the United Nations should strive to

investigate possibilities under which institutes in developing countries might benefit from existing reduced subscription rates for professional and popular journals. Alternative routes to enhance the availability of this critically important information in developing countries should also be investigated, such as the extension of the initiative taken by some journals, which are available to Latin American institutes at the individual scientist subscription rate.

14. In view of the severe difficulties encountered by researchers in acquiring textbooks, conference proceedings and other materials needed to maintain advanced scientific research, the United Nations should ensure the printing, in association with activities already being carried out by the International Astronomical Union (IAU), the International Centre for Theoretical Physics (ICTP), the European Physical Society (EPS) and the American Institute of Physics (AIP), of textbooks in Spanish and Portuguese on basic space science at the elementary, primary, secondary and undergraduate levels, as well as popular texts on basic space science in those languages.

2. Data archives and data centres

15. The participants emphasized the importance of the availability at the national level of existing basic space science data archives for building up first-rate educational and research capabilities for internationally recognized scientific investigations.

16. The United Nations therefore should urge Member States to select, through internal (national) discussion, local or regional clearing-houses for the highly valuable data archives that are still available at no cost from their producing agencies. The owners should be requested to deliver such data products in a manner conducive to easy dissemination and access at the national level, e.g., the International Ultraviolet Explorer (IUE), the Uniform Low Dispersion Archive (ULDA) and the Planetary Data System (PDS). These clearing-houses (or data centres) would foster the development of national basic space science resources and stimulate international collaboration through the existence of centres of common interest. They would also make highly valued data pertaining to individual countries more accessible to other countries, and consequently enhance awareness of the capabilities of each country.

3. Information management system

17. The participants noted that the United Nations had consulted with institutes and researchers concerning the availability of the above information and the collection of detailed information on bilateral and multilateral arrangements allowing the exchange of students and researchers for learning as well as for teaching purposes. A document containing this information was distributed at the meeting.

18. Recognizing that a country's level of involvement in the activities in basic space science is invariably associated with existing economic conditions, the participants recommended the development of new initiatives originating in developing countries for deeper involvement in basic space science. They recognized, however, that such new initiatives should be accommodated within the existing individual infrastructure of the country. It is important to explore ways and means through which continued evolution of individual countries' basic space science activities and international cooperation could be maintained and stimulated.

4. Electronic communication network

19. The participants recognized that the rapid pace of change in basic space science and technology makes the free and efficient flow of ideas and concepts a prime need for participation in basic space science, and therefore urged Member States to plan and implement local electronic communication at or above the level of E-mail networks. Once implemented, or even before the existence of a local (national) network, an internet/μnet/bitnet connection should be established at a suitable location.

20. The United Nations should request Member States to identify support needs without which the above-mentioned facilities cannot be implemented and should act to identify and possibly supply the limited funding needed to support justified requests for the minimum necessary investment to start the implementation of the fundamental needs associated with this.

5. Use of available scientific databases

21. The participants recognized the importance of access to advanced instrumentation and modern extended data sets for the evolution of basic space science disciplines and urged Member States and their scientists to utilize those facilities that are currently available. Much of this could be accomplished through the utilization of existing available databases (such as exist for IUE and EXOSAT and have now become available from the planetary missions), but additional direct use of these facilities would add critical impetus to the development of institutions currently unfamiliar with these facilities.

22. The United Nations should request the scientific institutes that are operating major basic space science facilities to respond to and support requests from developing countries for access to advanced instrumentation and to overcome, in all ways within their capabilities, the perceived problems of gaining access to their facilities.

23. The distribution and acquisition of software, especially in relation to the techniques related to data acquisition, data reduction, image processing and physical modelling, which has already been developed, can save considerable investment.

C. Availability and establishment of scientific facilities

1. Utilization of infrastructural facilities

24. In order to stimulate the utilization of the existing major facilities in basic space science by scientists from developing countries and to enhance their awareness, the United Nations should:

(a) Encourage countries possessing better facilities to open them to developing countries;

(b) Provide short-term fellowships and travel grants for such purposes;

(c) Stimulate the strengthening of the established facilities with specific expertise in the developing countries, so as to promote the existence of regional centres of expertise. These can act as catalysts and training centres for the development of global as well as regional research in basic space science. These centres should strive to stimulate the information flow in their region (e.g., information on institutes and active scientists, funding sources, etc.). Coordination of a regional fund for student exchange in a well-organized programme would be an important contribution.

2. Utilization of ground-based facilities available in developing countries

25. Considering that: (a) the climatological and geographical situation of the Latin American countries presents unique opportunities for observations in basic space science, of which only a few are currently being realized, with very limited access possibilities for the developing countries of the region; (b) there are countries where there is a great demand for observing facilities; and (c) there is technology available in some developing countries to build the instruments and detectors for use at recognized sites, the United Nations should encourage Member States:

(a) To share the existing telescope access with the scientists from the region;

(b) To develop such locations and stimulate the construction of advanced instrumentation, utilizing the techniques identified for basic space sciences;

(c) To improve the rocket and balloon scientific launch facilities in Latin America and to generate support for a strong regional programme in high-energy astrophysics and *in-situ* ionospheric studies;

(d) To develop methods which will assure efficient use of these facilities and encourage the major space agencies to support developing countries' initiatives in the field.

26. In order to help in the development of space science and technology in Latin America, the United Nations should support:

(a) The participation of Latin American technology in the space science projects of the major space agencies;

(b) Hardware development in Latin American countries for these projects.

D. International cooperation in basic space science

1. International cooperation and internationally coordinated basic space science programmes/projects

27. The United Nations should publish a regional directory of basic space scientists and institutions in Latin America. Information on possible sources of funding for training and research support for the different countries will be collected and included in the directory.

28. The United Nations, recognizing that the benefits of the pursuit of basic space science investigations constitute a prime mover of collaboration between Member States, should therefore support and recommend:

(a) Further expansion and continuation of studies of Equatorial Electrojet (EEJ) and the South Atlantic Geomagnetic Anomaly in the context of regional/international collaboration involving:

(i) The reactivation of selected geomagnetic and ionospheric observatories, as well as enhanced support of the networks of such observatories;

(ii) Encouragement of active scientists to participate in and organize international meetings;

(iii) The creation of national committees for the Committee on Space Research (COSPAR) for those Member States not already belonging to that organization, which is a major venue for the coordination of studies in the field;

(b) Development and construction of optical telescopes and radio telescopes with observatory facilities by the Latin American countries for use by the basic space scientists from the region;

(c) Augmentation of the global coverage of INTERMAGNET by supporting the establishment of three observatories in Sri Lanka, eight in Africa and eight in Latin America and the Caribbean;

(d) The establishment of a regional information centre specifically oriented towards astrophysics and atmospheric and geoplanetary sciences for the purpose of:

(i) Disseminating all relevant data obtained under basic space science activities such as remote sensing, atmospheric probing, astrophysics and geophysics to provide vital regional information of fundamental importance for addressing problems related to disaster avoidance and warning;

(ii) Developing a new understanding of the globally important equatorial zone, and therefore developing a plan (in the developing countries) leading to improved resource management and an improvement in living conditions;

(e) Strengthening and reorienting current research activities in the fields of solar-terrestrial, atmospheric and climatic studies, combined with space remote-sensing observations and comparative planetary sciences with participation in the internationally coordinated Global Change and associated programmes such as START, including:

(i) Satellite observations to assess pollutant-rich areas;

(ii) Ground and air truth measurements of solar radiation related to a variety of minor constituents;

(iii) Physical understanding and mathematical modelling of the interlinked processes of global change;

(f) Strengthening current research activities in the fields of astronomy and astrophysics, including:

(i) Experimental, observational and theoretical astrophysics;

(ii) Participation of Latin American astrophysicists in world-wide IAU-supported programmes;

(iii) Systematic galactic and extragalactic observations from equatorial latitudes and the southern hemisphere over the entire electromagnetic spectrum.

29. The participants recognized the difficulties existing in smaller developing countries relating to maintaining and participating in the technological and social developments following naturally from a viable programme in basic space science. They also recognized the problems associated with the relative isolation in which scientists pursue their efforts in these cases. The United Nations should therefore support:

(a) Organization of regional connectivity through data networks;

(b) Stimulation of institutional relations between those regional centres of expertise and local institutes to allow the build-up of a national capability to participate in the rapid scientific, technical and associated cultural development in the world;

(c) Training and further development of human resources, to stimulate and enhance the participation in a balanced development, even for smaller countries;

(d) Active stimulation of students in basic space science through participation in exchange programmes on a regional basis, as well as the exchange of prominent teachers and high-level technicians on a regional basis;

(e) Efforts to create awareness of the importance of basic space science in both decision-makers and the general public.

30. The participants deplored the indiscriminate destruction of carefully built-up infrastructure for basic space science through unstable social conditions. Such destruction was deemed to be considerably more destructive than just the material damage suffered, since important opportunities for rapid progress were lost. The significance of basic space science as a driving force in social renewal was recognized. Basic space science should be carried out with stronger conviction by scientists, and should be associated with more extensive general dissemination programmes.

2. Meetings and symposia on basic space science

31. Considering the growing interest and contribution made by several developing countries in basic space science and the need for further encouraging such activities, the United Nations should organize and support international meetings for in-depth discussions on specific topics of basic space science.

3. Continuation of the workshop on basic space science

32. In order to assure a continued and coordinated evolution of the important issues raised in the present and the previous workshop, it was proposed to hold future basic space science workshops annually, although in the long run they should be held no more than biannually.

33. The United Nations should inquire into the possibilities for hosting the next basic space science workshop in 1993.

4. Space education

34. Considering that basic space science is not taught at superior levels in many developing countries, the United Nations should act to encourage and support:

(a) Introduction of the teaching of basic space science, including experimental techniques, as a part of the curriculum for primary and secondary level education as well as undergraduate and graduate education;

(b) Formation of research facilities at universities so that motivated students may be encouraged to pursue basic space science research;

(c) Organization of summer schools and other similar orientation programmes to train existing faculty in the physical sciences necessary to teach basic space science;

(d) Exchange of teachers, scientists and students to make use of the facilities in Member States and the services of organizations such as IAU and COSPAR;

(e) Organization of seminars, workshops and topical conferences within the developing countries for the benefit of teachers, scientists, students and the general public;

(f) Introduction of popular programmes to encourage and support awareness of basic space science, and the coordination of such activities between Member States;

(g) Establishment of programmes ensuring the availability of basic textbooks and more popular information media at the professional and general public levels;

(h) Distribution and acquisition of educational software for basic space science;

(i) Generation of national career opportunities for professionals trained under the above-mentioned programmes, leading to increased competitiveness of developing countries in the peaceful study and utilization of resources associated with basic space science.

5. International core group

35. In order to pursue and follow up the recommendations made during the Workshop, it has been decided to constitute a core group, under the auspices of the United Nations (Office for Outer Space Affairs), of international scientists consisting of the following members at the functional and advisory levels:

Functional members: Selection of a group of 11 members from the five economic regions and the United Nations

Advisory members: COSPAR, ESA, IAU, ICTP, National Space Development Agency (NASDA) of Japan, National Aeronautics and Space Administration (NASA) of the United States of America.

The creation of the international core group is considered critical to maintaining the impetus generated by the first two workshops on basic space science for the benefit of the developing countries, and will assure the continuity of this important activity in the future.

Annex I

SUMMARY OF PRESENTATIONS

A. Origin of the solar system

1. Star formation. The process of star formation is a very complex and challenging one, among other things because one cannot observe it directly; it occurs deep inside dense cool and opaque nebulae, as if nature were so shy to hide it from the observer's view. To understand how stars are formed one has to rely on what can be observed long after they have emerged from their cocoons; unfortunately sometimes, the clues have been contradictory and misleading. The main observational clues starting from those more removed from the period of star formation and giving to the more intimate views as revealed by infrared and radio observations have been described and discussed. The present understanding of star formation to the cosmogony of double star and planetary systems was stressed.

2. Origin of the solar system. (i) Formation of the terrestrial planets and asteroids: Recent work on planet formation in the terrestrial planet region provides support for models in which planetary growth occurs in two fairly distinct stages. 1. A ''low velocity'' stage in which (at 1 Astronomical Unit [AU]) runaway Moon to Mercury-mass objects grow from 10 km diameter planetesimals on a $\approx 10^5$ year timescale. This timescale lengthens with increasing distance from the Sun, but within a few million years, it is expected that 100-200 such ''embryos'' will form in nearly circular, coplanar orbits in the terrestrial planet region and in the asteroid belt. 2. A ''high velocity'' stage in which these embryos perturb one another into crossing orbits and to velocities ranging from a few km/sec to - 30 km/sec. During this stage, collision and merger of embryos form the terrestrial planets on a $\approx 10^8$ year timescale. Assuming that growth of Jupiter occurs too late ($\geq$1 million years) to prevent the formation of runaway embryos in the asteroid belt, removal of excess mass from the asteroid belt primarily will take place via perturbation of embryos into Jupiter commensurability resonances, followed by ejection from the solar system. If somehow Jupiter was able to restrict the growth of bodies in the asteroid belt to objects the size of the present asteroids, then the clearing of the asteroid belt will probably depend on collisional fragmentation and removal by Poynting-Robertson drag. It may prove possible to distinguish between these alternatives by quantitative inferences based on asteroidal and meteoritic observations.

3. Origin of the solar system. (ii) Formation of the giant planets: Formation of the gas giants, Jupiter and Saturn, differs considerably from that of the terrestrial planets. To form these planets it is probably necessary that: Very massive (10-15 Earth masses) planetary embryos formed by runaway accumulation in $\approx$ 5x

10^6 years. Initiation of a "gas accretion" instability whereby gas (primarily hydrogen and helium) was gravitationally captured by the embryos to form 300 and 100 Earth mass planets. Both of these stages must occur rapidly, before loss of gas from the Solar Nebula in $\approx 10^7$ years. Quantitative calculations show that these events are possible given appropriate distribution of solid material and timing of gas removal. On the other hand, variations in these parameters might cause the formation of planets like Jupiter and Saturn to be fairly rare in other planetary systems. Nevertheless, it may not be surprising that these planets are observed in the solar system. Gas giants provide a gravitational barrier that shield the terrestrial planets from bombardment by comet-like bodies of the primordial outer solar system. Such shielding may be necessary to prevent impact frustration of the evolution of the more complex biological organisms. Little quantitative study has been given to the formation of Uranus and Neptune. Perhaps the most satisfactory models involve the formation of ≈15 Earth mass embryos on a 10^7 - 10^8 year timescale, followed by capture of a relatively small quantity of residual gas from the solar nebula. It is likely that perturbations by the prior-formed giant planets Jupiter and Saturn would preclude bodies of this kind within ≈20 AU and paucity of solid material prevented planet formation at much greater distances.

B. Terrestrial interactions

4. Magnetospheric plasma interactions. The Earth's magnetosphere (including the ionosphere) is the nearest cosmical plasma system and the only one accessible to mankind for extensive empirical study by *in situ* measurements. As almost all matter in the Universe is in the plasma state, the magnetosphere provides an invaluable sample of cosmical plasma from which one can learn to better understand the behaviour of matter in this state, which is so much more complex than that of non-ionized matter. It is therefore fortunate that the magnetosphere contains a wide range of different plasma populations, which vary in density over more than six powers of ten and even more in equivalent temperature. Still more important is the fact that the dual interaction with the solar wind above and the atmosphere below make the magnetosphere the site of a large number of plasma phenomena that are of fundamental interest in plasma physics as well as in astrophysics and cosmology. The interaction of the rapidly streaming solar wind plasma with the magnetosphere feeds energy and momentum, as well as matter, into the magnetosphere. Injection from the solar wind is a source of plasma populations in the outer magnetosphere, although much less dominating than previously thought. One now knows that the Earth's own atmosphere is the ultimate source of much of the plasma in large regions of the magnetosphere. The input of energy and momentum drives large scale convection of magnetospheric plasma and establishes a magnetospheric field and large scale electric current systems that carry millions of ampere between the ionosphere and outer space. These electric fields and currents play

a crucial role in generating one of the most spectacular among natural phenomena, the aurora, as well as magnetic storms that can disturb man-made systems on ground and in orbit. The remarkable capability of accelerating charged particles, which is so typical of cosmical plasmas, is well represented in the magnetosphere, where mechanisms of such acceleration can be studied in detail. In situ measurements in the magnetosphere have revealed an unexpected tendency of cosmical plasmas to form cellular structure, and show that the magnetospheric plasma sustains previously unexpected, and still not fully explained, chemical separation mechanisms, which are likely to operate in other cosmical plasmas as well.

5. Asteroids and comets. These small rocky, metallic, and icy bodies are the remnants of the population of planetesimals from which one believes the planets formed. Spacecraft studies of these small bodies have been initiated in just the past few years, with several investigations of comet Halley and the Galileo spacecraft's recent encounter with the asteroid Gaspra.

6. Meteorites. Every year, more than 100 tons of meteoritic material impacts the Earth. Almost all of these objects are fragments produced by collisions between asteroids. They represent an intermediate-mass portion of a spectrum of asteroidal debris that ranges from 1 to 10 km diameter near-Earth asteroids down to micro-size asteroidal zodiacal dust. Detailed study of these meteorites in the laboratory shows that the asteroids from which they are derived are very primitive bodies. Radiometric dating shows that the crystallization or metamorphism of these rocks occurred 4.45 to 4.55 billion years ago, for the most part before the formation of the Earth. As a consequence, they bear an exquisitely detailed record of events and processes in the early solar system, in the solar nebula, and even contain relics of pre-solar interstellar events. Full use of this remarkable record requires placing the meteorites studied in the laboratory into their planetological context identifying the asteroids from which they are derived, understanding the mechanisms by which the asteroidal fragments are delivered to Earth, and incorporating the formation of the asteroids into a general theory of the formation of planetary systems. Major progress has been achieved on all these problems, but there remain serious unresolved questions. Perhaps the most important of these is the reason why spectrophotometric observations of asteroids seem to imply the near-absence of asteroids with the composition of the most abundant type of meteorite - the "ordinary chondrites".

7. Catastrophic impacts on Earth. The Earth and Moon reside in a swarm of asteroids and comets, which collide and explode from time to time, as revealed by the cratered surface of the Moon. While Earth's atmosphere filters out the smallest impactors, and geological forces have destroyed evidence for many earlier impact craters, the fragile ecosphere of the planet Earth can be dramatically altered by these catastrophic events. A 15 km sized

object apparently impacted near the Yucatan peninsula of Mexico 65 million years ago, and was responsible for mass extinctions of many species of life. Evolution of mammals developed rapidly thereafter, culminating in modern civilization. But the odds are about 1 in 10,000 that modern civilization will be destroyed during the next century by a future impact, unless one takes steps to discover the threatening objects and avert any impending calamity.

8. Volcanoes on the Earth and planets. Comparative volcanology between the Earth and the planets has been addressed as an introduction to the field trip to Poas volcanoes. It has been stressed how studies of terrestrial volcanic fields can be used to interpret features on other planets and discussed various models developed from terrestrial studies which have been applied to interpret the formation of lava flows and other extraterrestrial volcanic features.

C. The terrestrial planets

9. Surface processes - Volcanism and tectonism. The major processes shaping the surfaces of the terrestrial planets are volcanism, tectonism, impact cratering, and erosion. It was discusses how volcanism and tectonism have produced a wide variety of landforms on Mercury, Venus, the Earth's Moon, Mars, and on outer solar system satellites. The influence of planetary parameters on how these processes operate was also addressed and comparisons with the Earth had been made.

10. Surface processes on planets and satellites. With the "flyby" of the Neptune system in the late 1980s by the Voyager spacecraft, all of the planets and major satellites in the solar system have been explored by robotic spacecraft. Geological analyses of the data returned over the past quarter century of solar system exploration has shown that solid surface planets and satellites are modified by a wide variety of processes. The processes can be categorized as (i) endogenic processes originating primarily as a result of heat in the interior of the object under consideration; these processes include volcanism and tectonism, and (ii) exogenic processes originating from exterior sources to the object under consideration; these include impact cratering and surface modifications by wind, water, gravity, etc. In this presentation, consideration had been given to exogenic processes. Evidence for impact cratering is seen for all of the objects in the solar system except the Galilean satellite of Jupiter, Io, which appears to be undergoing very active volcanism, which has obliterated all traces of impact scars. Those planets having dynamic atmospheres experience aeolian, or wind, processes and include Mars, Earth, Venus, Triton (satellite of Neptune), and possibly the Saturnian satellite, Titan. To varying degrees, exogenic processes have modified the surfaces of all planets and satellites.

11. The planet Mercury. Mercury is an extreme planet, a small, metal-rich world bathed in the glare of the Sun. Yet Mercury is a world of surprises, such as the recent discovery of what may be ice caps near its poles.

12. Venus - Exploration via spacecraft. More than two dozen missions have been flown by the United States of America and the former Soviet Union in the exploration of Venus. Spacecraft include landers that have survived on the surface, various "flybys", and orbiting spacecraft that have returned global data for Venus. Data from these missions, combined with various Earth-based observations, have revealed a great deal of information on the nature of the Venusian atmosphere and surface. Because of its similarity in size and mass to the Earth, it is often called the Earth's "sister" planet. Prior to the successful operation of the Magellan spacecraft, there was a great deal of speculation about the potential for Earth-like processes, including plate tectonics and volcanism. Although the geological diversity of Venus was hinted at through the Venera 25/16 radar data, the Magellan mission has provided the first comprehensive view of the complete geological history of Venus. Although volcanic and tectonic processes dominate, exogenic processes, including modification by the wind, are also in evidence. Analysis of the Magellan data is continuing through systematic geologic mapping, topical studies and analysis of geophysical data.

13. Mars - The red planet. After Earth's satellite, the Moon, the planet Mars is probably the best understood of the terrestrial planets in the geological context. Numerous spacecraft have been sent to Mars, including ''flybys'', orbiters, and landers. The first comprehensive view of Mars was gained by the Mariner 9 mission, which began operation in 1971. This successful mission was followed by the landing of the two Viking spacecraft and operation of two orbiters in the mid 1970s. From these missions, the geological history of Mars has been derived. Clear evidence exists for drastically different climates in the past, including times when surface water existed to carve enormous river channels, now left dry. Huge volcanoes dominate the landscape in some areas, while still other regions have been modified extensively by crustal disruption or tectonic processes. Renewed interest in Mars has been prompted by the launch of the Mars observer spacecraft, anticipated in late September 1992. This mission carries an array of instruments to provide global maps of the composition and mineralogy of the surface, insight into the nature of the atmosphere, and topographic data, as high resolution images of the surface. This mission is anticipated to be followed by the Russian Mars 94/96 missions, the Mars Environmental Survey Mission of the United States of America (later this decade), potential European missions involving emplacement of network science instruments, such as seismometers, and the possible launch of a Japanese spacecraft. These approved and anticipated missions demonstrate the high interest by the international community in the exploration of Mars.

14. Mars Observer - A geological and climatological mission. The Mars Observer (MO) spacecraft began its journey to Mars in September 1992 and is scheduled to arrive at Mars in August 1993. The Mars Observer carries a scientific payload of seven instruments that will observe the red planet for one Martian year (687 Earth days) from a 375 km altitude circular polar orbit. The mission will gather information about the Martian atmosphere, surface composition, and help settle the debate over the existence of a magnetic field. The Mars Observer will also participate in the relay of data from a Russian mission to Mars in 1994-95.

15. The special case of Io. Jupiter's satellite Io is of great interest to the topic of planetary volcanology as it is the only extra-terrestrial body known to have large-scale active volcanism. Io's activity, which is thought to be driven by tidal heating, was first detected by the Voyager spacecraft in 1979. The two Voyager encounters provided a wealth of information on Io's volcanic behaviour, however, many questions remain open. Current research work focuses on the current debate about Io's surface composition, reviewing what is known so far from the Voyager data, and discussing the expected results from the Galileo mission, respectively.

D. The Sun

16. Internal structure of the Sun. The Sun as a main-sequence star continuing to be the probe for new ideas in stellar astronomy and physics. The classical solar neutrino problem has been established by the chlorine solar neutrino experiment (USA) over the past 20 years. Additionally, the anti-correlation between the abundance of sunspots and the argon-37 production rate in the chlorine experiment remains to be explained in terms of new neutrino properties or new solar physics. The Kamiokande II experiment (Japan) confirmed the deficit of high energy solar neutrinos as revealed by the chlorine experiment. Most recently, the GALLEX 1 experiment (international collaboration) measured the low-energy solar neutrino flux which seems to be not varying over time and not correlated with solar activity. Based on the conjectured simple internal structure of the Sun, governed by a hydrostatic component and a luminosity-opacity component, much insight has been gained from simple polytropic models such as Eddington's model. Models of the Sun can be constructed for which a non-linear analytic density distribution in terms of a two-parameter family is assumed, for which the system of differential equations for the internal structure of the Sun can be integrated analytically. Hydrostatic equilibrium and energy conservation determine the conditions in the gravitationally stabilized solar fusion reactor. Explicit analytic results obtained for the pressure and temperature distribution in the central region of the Sun can be compared with numerical results emanating from what has come to be known as the Standard Solar Model (SSM).

17. The gallium experiment - Status and first results of GALLEX. The GALLEX experiment for the detection of solar neutrinos by means of a radiochemical gallium detector is operated by groups from Italy, France, Germany, Israel and the United States of America in the Gran Sasso underground laboratory (LNGS) near L'Aquila (Italy). It consists of (i) the target tank containing 101 t of a highly concentrated $GaCl_3$ solution, (ii) a sparking system for desorption of $GeCl_4$, (iii) the absorption system for concentration of $GeCl_4$, (iv) the laboratory scale apparatus for conversion of $GeCl_4$ to GeH_4, (iv) the counter filling station, and (vi) the counters. Possible side reactions by cosmic muons, fast neutrons and α-emitters interfering with the neutrino measurement have been discussed, as well as the purification of the target solution from long-lived, cosmogenic ^{68}Ge. First preliminary results after one year of solar neutrino measurement were presented; they constitute the first measurement of the solar proton-proton neutrinos and amount to 83 SNU (Solar Neutrino Units) ± 19(stat.) ± 8(syst.) (1σ). The measurements including the calibration with a ^{51}Cr-source are continuing.

18. Applications and computational considerations of special functions to solar thermonuclear reaction rate integrals. The first application of Gamow's theory of potential barrier penetration to other than his study of alpha radioactivity was to the thermonuclear source of stellar energy. Atkinson and Houtermans were the first to propose that nuclear reactions may take place in the central region of stars where the motion of nuclei can be assumed to be in thermal equilibrium. The thermonuclear reaction rate between two types of nuclei can be written as $r_{12}=(1-1/2\ \delta_{12})n_1n_2\langle\sigma v\rangle_{12}$, where n_1 and n_2 are the number densities of nuclei of type 1 and type 2, and where $\langle\sigma v\rangle_{12}$ is the reaction probability which is related to the product of the reaction cross section and the flux of particles, averaged over the Maxwell-Boltzmann velocity distribution. As theoretical knowledge and experimental verification of nuclear cross sections increased it was possible to refine the analytic representations for the reaction probability $\langle\sigma v\rangle_{12}$ as derived over the years by Gamow (1949), Bahcall (1966), and Critchfield (1972). These formulae are approximations chosen to be applicable under certain well defined physical conditions. The first approach to derive close-formed representations of the reaction probability was made by Mathai and others. They have shown that, in principle, the reaction probability contains the astrophysical cross-section factor S(E) and its derivatives which has to be determined experimentally, and an integral part of the thermonuclear reaction rate independent from experimental results which can be treated by closed-form representation techniques in terms of generalized hypergeometric functions. Under the Maxwell-Boltzmann approach, the study of nuclear reactions in astrophysical plasmas under various cases (such as resonant, non-resonant, modified non-resonant, non-resonant under electron screening, and so on) leads to a class of complicated reaction rate integrals. It has been shown that this

general class of integrals can be identified with an integral involving the product of two H-functions. This latter integral has been evaluated and computational considerations were provided, including the relative merits of Mathematica and C-compilers for making these computations.

19. Solar neutrinos in relation to solar activity. A serious discrepancy exists between the theoretical value of the solar neutrinos flux calculated from current standard solar models and that obtained from the production of ^{37}Ar atoms at the Homestake station over a period of almost a quarter of a century. Many solar phenomena exhibit variation in the rhythm of the solar cycle. Relation between solar neutrino and solar activity has been investigated by many researchers who have reported contradictory results of correlation, anti-correlation and no correlation. It can be shown that a statistically significant correlation between solar neutrinos and charged particles from the Sun received on Earth exist.

20. Changes in solar irradiance and atmospheric turbidity in Costa Rica during the total solar eclipse of 11 July 1991. Solar global radiation was measured in several places in Costa Rica during the total solar eclipse that occurred on July 11, 1991. In two of these places, Puntarenas and Santa Cruz, measurements in the ultraviolet range (295 - 385 nm) were also taken. In Santa Cruz, a normal incidence pirheliometer with Schott filters OG530 and RG630 was used to measure direct solar radiation in its whole range and in the 530 - 2800 nm and 630 - 2800 nm wavebands, respectively. Global radiation, and consequently direct, diffuse and irradiance in any of the wavebands considered, decreased gradually as the Sun was being eclipsed, and reached zero during the totality, then increased to their normal values. Data registered in Santa Cruz were used to determine Angstroem's atmospheric turbidity parameters α and β. Computations show that between 13:00 and 14:30 local time α decreased and β increased significantly. The values of α and β indicate that on this particular day atmospheric turbidity was high and large particles were more abundant than small ones. The size of hygroscopic particles increased during the eclipse when temperature decreased and relative humidity increased in a relatively short time.

21. Variation of the geomagnetic field in Costa Rica during the total solar eclipse of 11 July 1991. Observations of the geomagnetic field were carried out in three places of Costa Rica, which were located in the path of totality. The observations show that close to totality, it was a significant change in the total intensity, F. Its normal decrease in the afternoon hours was interrupted during a period of about 45 minutes, in which F changed very little. This was due mainly to the small variation in the horizontal intensity, H, during such a period. The deviation of F with respect to normal lasted about 100 minutes; its maximum deviation was about 10 nT and occurred 38 minutes after totality.

The declination, D, also had a small change (an amplitude of about 2.3 minutes) during all the duration of the eclipse. The vertical intensity, Z, and the inclination, I, did not show significant changes.

E. The outer planets

22. Jupiter. This is the largest planet in the solar system, with at least 16 satellites - one bigger than Mercury, one about the same size, and one with active volcanoes - a huge magnetosphere and a system of rings. Jupiter has too little mass to become a star, but still releases more heat from its interior than it receives from the Sun. The changing, colourful cloud patterns one sees in its hydrogen-helium atmosphere provide evidence for chemical reactions among the atmospheric constituents. Heavy elements are slightly enriched in Jupiter's atmosphere, compared to their abundances in the Sun.

23. Saturn. Famous for its rings since Huygens identified them in the 17th century, Saturn is perhaps the most familiar planet. The Voyager missions found much intricate structure in the rings and examined some of the 18 satellites, including mysterious Iapetus, with one hemisphere nearly 10 times darker than the other and Enceladus, closely associated with the E-ring. The internal source of energy on Saturn appears to be the condensation of helium in the planet's deep interior, resulting in a helium deficiency in the atmosphere. Heavy elements in Saturn's atmosphere appear to be enriched compared with the values on Jupiter, but this general trend has exceptions not yet understood. Both Jupiter and Saturn appear to have retained the primordial deuterium to hydrogen ratio that existed in solar nebula gas.

24. Uranus. This planet is different from all the other giants. Lying nearly on its side as it orbits the Sun, it has no detectable internal energy source. 15 satellites circle Uranus in its equatorial plane, where one also finds a system of narrow rings close to the planet. The atmosphere shows a large enrichment of methane and deuterium, compared with Jupiter and Saturn. Unlike these other giants, the visible atmosphere of Uranus is remarkably free of clouds. The planet's magnetic field is oriented at a surprisingly high angle to its axis.

25. Neptune. Like Uranus, Neptune represents a giant planet with a higher density than that of Jupiter and Saturn, again showing a large enrichment of methane and deuterium in its atmosphere. Neptune has 8 known satellites, and a strange ring system that includes discrete arc-like structures in one of the rings. The planet's magnetic field exhibits a similar eccentric orientation to that of Uranus. Unlike its sister planet, however, Neptune does have an internal source of energy. Perhaps as a consequence of the resulting greater vertical convection, the stratosphere of Neptune contains HCN and CO.

26. Pluto, Triton, and Titan. These three objects are grouped together because they are all icy bodies with nitrogen-dominated atmospheres. Although Pluto is usually classified as a planet, (after all, it orbits the Sun and has a satellite!) it is actually smaller than either Triton or Titan. The atmospheres of these bodies have some useful things to tell researchers about chemical evolution at low temperature that may be relevant to the delivery of volatiles to the early Earth. These objects may also be representative of the ''planetesimals'' that secreted to form the cores of the giant planets. Titan is a main focus of the Cassini-Huygens mission, currently under development as a joint ESA-NASA project.

27. Modelling the Jovian planets by a simple analytical algorithm. It can be shown that the structures of the Jovian atmospheres and cores can be modeled by a simple analytical algorithm, which does not require the use of a computer. The method known as the MDV (Motz-Doorish Variable) method was first reported in the Irish Astronomical Journal (1989). It is a method to solve the Stellar Interior Equations (SIE) which dictate the structure of a star and/or the Jovian planets. The results have been compared mainly, to the work of Stevenson (1982) and found to be very agreeable. Tabulated results of both the atmospheres and cores of Jupiter, Saturn, Uranus and Neptune have been provided. This method has also been applied to the protoplanetary stage.

28. Bodies of ice. Measurement of the low density, and the direct observation of surface ices for some planets, have encouraged the creation of planetary models having large mantles of ice surrounding a small rocky core. These models and possible effects on remote sensing of the surfaces of these icy bodies have been reviewed.

29. Surfaces of ice. Ices have been observed on most planetary bodies from Earth outward. The history of remote sensing of ices, techniques used to determine the existence and extent of ices on planetary surfaces, and the current understanding of the distribution, composition, and stability of ices within the solar system were discussed.

F. Life: A planetary phenomenon

30. Comets, interstellar dust and the origin of life. Over the past decade it has become clear that cometary dust as well as interstellar grains are predominantly comprised of complex organic material including aromatic and aliphatic structures. It is also generally conceded that the early Earth conditions were unfavourable for the production in situ of pre-biotic material. A connection between interstellar organics, comets and the origin of life, which was suggested as early as 1975 by Hoyle and Wickramasinghe, now appears to be inevitable. The question that remains to be resolved is whether extraterrestrial pre-biotic

material arrived to be assembled into living systems, or is it likely that preformed self-replicable living structures arrived from outside?

31. Why visit Titan and Europa? The special attraction of Titan for studies of the origin of life stems from the fact that this large satellite of Saturn has a reducing atmosphere in which chemical evolution is taking place today. Simple compounds such as methane and nitrogen are being broken apart by electron bombardment and solar ultraviolet light and the fragments of these molecules are forming more complex substances. One can see the first steps in this process in the small molecules discovered by Voyager 1: C_2N_2, C_3H_8, etc. One knows larger molecules are being formed because they make up the aerosol that fills the atmosphere. One wants to know what these compounds are and what pathways were taken to produce them. Europa interests us because it may have a layer of liquid water immediately below its icy crust. If so, it is important to know whether or not any chemical evolution is occurring in this environment.

32. Synthesis of organic compounds - A simulated Titanian atmosphere: An educational model. An inexpensive and practical model for teaching about biochemistry and the origins of life was described. In the 1950's Stanley Miller performed an experiment in which gases assumed to compose the primary Earth atmosphere were placed in a glass vessel. They were then energized with "artificial lightning". The results were many organic compounds, which thus proved the processes of chemical evolution. The same type of experiment can be performed on a simulated Titanian atmosphere which if/when successful can show that organic chemistry is possible on Titan. The apparatus is inexpensive as are the chromatography techniques, which makes this type of research very valuable to students in developing countries.

33. Life on Mars. Although the Viking results may indicate that Mars has no life today, the possibility exists that Mars may hold the best record of the events that led to the origin of life. There is direct geomorphological evidence that in the past Mars had large amounts of liquid water on its surface. From a biological perspective the existence of liquid water, by itself, motivates the question of the origin of life on Mars. From studies of the Earth's earliest biosphere one knows that by 3.5 Gyr. ago, life had originated on Earth and reached a fair degree of biological sophistication. If Mars did maintain a clement environment for longer than it took for life to originate on Earth, then the question of the origin of life on Mars follows naturally. Studies in the Antarctic and the Siberian permafrost provide lessons in how life on Mars may have persisted.

34. The origin of life in the solar system. Currently one lacks a fundamental theory for life and with only one example to study extrapolation is best based on ecosystems found on Earth. Field

studies of life on Earth - particularly in extreme environments - indicate that liquid water is the quintessential requirement for life. Thus, the presence of liquid water provides the most useful environmental criteria for searching for life on other planets. In the present solar system, liquid water, and hence life, is definitely found only on Earth. There is convincing evidence that liquid water existed on Mars early in its history. Europa and comets are speculative candidates for liquid water habitats. Mars, 3.5 Gyr ago, is the most promising site for life in our solar system other than the Earth.

35. Detectability of extraterrestrial civilizations activities. The possibilities to establish contact or detecting technological extraterrestrial activities according to the laws of nature as they are known has been reviewed. The efficiency among the boson astronomy (photons and gravitons), with particle astronomy (neutrinos, cosmic rays and macroscopic particles or objects) as well as the use of direct techniques (interstellar space probes or spaceships) were compared. Assuming that there is a certain number **N** of civilizations in the galaxy, at mankind's or beyond mankind's level of technical facility, and considering that each civilization is on or near a planet of a main sequence star where the asteroid/comet impact hazards is considered as serious as on Earth, the detectability of some of the "intelligent activities" developed by the extraterrestrial civilizations to warning these dangerous impacts using the present and near future SETI programs have been studied.

G. Cosmic physics

36. Astrometry in the Kerr field. The basis for a non-static relativistic astrometry, i.e. one in which one takes into account the rotation of the Sun has been studied. In order to accomplish such a task, the following procedure had been chosen: For this purpose the Kerr metric (interpreted as the space-time of a rotating body, with parameters M, a and angular momentum J = Ma) represents the field of the Sun (body with slow rotation). Then, expanding it in a power series of a, the resulting space-time (Lense-Thirring-like metric, with $J = J_z = I\Omega$) can be transformed again by means of the harmonic condition of the Schwarzschild metric. Thus, by adding the missing components of J through the definition of the vector potential V and expanding the space-time (quasi-harmonic form) in a power series of the gravitational field U, and by just keeping only the PPN order, allows to assign to each term of these new metric tensor components certain parameters or coefficients in agreement with post-post-Newton (PPN) theory, in order to have a workable metric for this purpose. The light rays path coming from a star and its corresponding gravitational time delay associated with it are calculated using the metric described above. Thus in order to achieve this the light deflection is divided in two parts: One that is parallel to the straight line path (this part is related with the associated gravitational time

delay) and the other perpendicular to the previous direction (it is related to how the light ray is deflected). The subsequent application of perturbation theory allows to find the solution (the post-Newtonian (PN) order was already found by Will) for the light rays path in the solar field, and associated with this result one obtains the gravitational time delay. The notion of the observer's rest frame and the stellar compass was presented. With the aid of the first concept one can determine the angle (independent of the reference frame) between two light rays (null vectors K and K'), one originating in the star, taken as the reference, and a second one from another star taken as the source (both rays projected onto the observer's rest frame). From this result one finds the PN, $P^{3/2}$ N and PPN contributions to the light deflection angle, when one moves the reference stars to the place where the Sun is located. Verification has been provided for the predicted values by Epstein-Shapiro for the light deflection of a ray that grases the solar limb. Furthermore, the tetrads of the Kerr metric in its parametrized PPN form have been chosen and applied to the formula for the angle between two light rays referred above with the purpose of determining the corresponding directional cosines (depending on the reference frame). In other words, the angle that a light ray, originating in a star (projected onto the observer's rest frame), forms in the local reference frame has been calculated. Additionally, one can calculate the PN, $P^{3/2}$ N and PPN contributions to the right ascension and to the declination that represent the position of a fixed star on the celestial sphere. Thus a stellar catalogue can be drafted.

37. A remark on the one-photon-pair annihilation in strong magnetic fields. Specific results on a quantum electrodynamical feature of the one-photon-pair annihilation which completes the calculations already done for this process have been reported. Most of the calculations related to this process have been usually carried out utilizing the wave functions obtained from the Dirac equation in the Landau gauge $\mathbf{A}_a = (0,B\,x,0)$, where B is oriented along the z-axis (Johnson and Lippman, 1949, referred to as JL). The eigenstates of the Dirac Hamiltonian as it was introduced by JL do not consider the coupling to the radiation field and consequently they reflect only for $p_z=0$ the same linear combination of the two degenerate polarization states. Furthermore, in subsequent publications where these eigenstates are employed, they must be considered with caution as far as cases with $p_z\neq 0$ and $N>0$ are concerned. Sokolov and Ternov (1968) have chosen wave functions which are eigenfunctions they called transverse polarization states of an operator which may be interpreted as the component of the magnetic moment of the electron operator along the external magnetic field B. The gauge chosen in order to get such eigenfunctions is $\mathbf{A}_b = (-By/2,\ Bx/2,0)$, where $\mathbf{A}_b = \mathbf{A}_a + \nabla\Lambda$ with $\Lambda = -Bxy/2$). The use of polar coordinates seems for this particular problem of particular interest. Further, there is another set of eigenstates used by Herold (1979) and Herold and collaborators (1983) that denominated the proper polarization states of the

electron which take into account the coupling of the electron to the radiation field by the interaction Hamiltonian, thus removing the degeneracy of the 2 polarization states in excited Landau levels. All this raised the question how the form of the transition rate depends on the choice of the gauge for the external homogeneous constant magnetic field and how the corresponding spinors couple to the external field when they are applied to a radiation process, i.e., one-photon-pair annihilation in external magnetic strong magnetic field. Additionally, Harding (1986) argued that the eigenstates used by Daugherty and Bussard (1980), which are the same as in JL, reproduce the correct results if the transition rate function will be averaged over the electron and positron eigenstates. Finally, the transition rate function for the one-photon-pair annihilation in a strong magnetic field using the Sokolov and Ternov eigenstate $| \pm >$, as far as $p_z = 0$ and $N > 0$ is concerned, was presented. The difference between the expression for the transition rate by using the Sokolov and Ternov eigenstates and the one calculated by Wunner and collaborators (1986), is just the function $I_{s,s'}$ which corresponds to the degeneracy of the orbit centre of the electrons characterized by the quantum numbers s and s'.

38. On the natural linewidth of absorption lines in strong stellar magnetic fields. In recent times the interest to explain the existence of a singularity at lower frequencies ($\omega=0$) in the differential cross section for scattering of photons by electrons, exposed to a homogeneous magnetic field, for the transitions between the Landau levels N and N', has greatly increased. A calculation of the cross section for the absorption of radiation by an electron in a strong stellar magnetic field in the Wigner-Weisskopf approximation, in order to explain this kind of singularities in the Compton cross section, has been given.

H. Cosmic Background Explorer (COBE): Observation and theory

39. Hydrodynamic stability and the formation of structures in the Universe. The role played by the linear and non-linear hydrodynamic stability (instability) in the formation (destruction) of cosmic structure (stars, clouds, stellar clusters, galaxies ...) was outlined. In particular, explicit criteria for supercritical stability, subcritical instability, asymptotic stability, and superexponential instability for thermal structures of interest in astrophysics have been discussed. Applications of the above general criteria to the primordial plasma, burning cores of star, the solar atmosphere and the interstellar medium (atomic and molecular clouds) were emphasized.

40. Evolution of perturbations after decoupling. A program for the reconstruction of density fluctuations and peculiar velocity field maps for different values of z (the redshift), from the time of matter-radiation decoupling up to the present epoch has been reviewed. The recent measurement of the sky map for temperature

fluctuations of the Cosmic Background Radiation (CBR) provides, at least in a statistical sense, "initial conditions" for the origin of structure in the Universe. On the other hand, during the last few years there has been a growing number of data about the distribution and peculiar velocity of matter for $z \leq 5$, which gives much information concerning the non-linear phase of the evolution of large-scale structure. Analytical methods can be employed to simulate this phase. Such equations, and other important relations among relevant variables, have been developed through the use of the BBGKY hierarchy, or integrations of moments of the Vlasov equation. Some of the simplifying assumptions made, such as self-similarity and scale invariance, were not taken up as an integral part of the computational scheme, but instead were left to justify themselves as a possible outcome of the strongly non-linear regime. Moreover, "virialization" of different parts of the matter distribution was expected to come naturally out of the evolution of the system without the need to impose a special form of the solution for the peculiar velocity field. Finally, it was checked whether this approach connects smoothly with the underlying assumption in present calculations of the peculiar velocity field, such as in POTENT, where the velocity field, averaged over some large scale, can be derived from a potential scalar function.

41. Computational aspects of the gravitational instability problem for a multicomponent cosmological medium. To explain the observed large-scale structure of the Universe, the clusters of galaxies and conglomerates of them, the cosmological models require some input that the early Universe contained density fluctuations from which such large-scale structures might grow. Recently, COBE found a temperature variation $\Delta T/T=6 \times 10^{-6}$ in the cosmic microwave background that can be taken as a surrogate for density perturbations from a time well before the separation of radiation from matter. The COBE result seems to be consistent with theories of large-scale structure formation that are dominated by nonbaryonic dark matter. Three main types of particles take part in the formation of structure in the Universe as well as in governing its subsequent development at about 10^4 years after the Big Bang, a time when matter density becomes equal to radiation density and when radiation domination is over: particles of nonbaryonic nature composing dark matter, baryons, and photons. Newtonian theory can be used for the description of the evolution of small perturbations in a multicomponent medium thereby assuming that all velocities are small compared to the speed of light. Closed-form representations of the solutions of the linear perturbation equations have been presented. These representations, which are valid for irregularities on any scale, can be used to analytically interpolate between known approximate solutions which are valid for large-scale (early time) inhomogeneities and for small-scale (late time) inhomogeneities. Methods to derive computable forms of the perturbations are outlined.

42. Mapping the galaxy: The Andes-Berkeley-INPE project. Mapping of the diffuse radio emission of the Milky Way is not only important in its own right but also necessary for the analysis and interpretation of Cosmic Background Radiation data. It was shown that measurements of anisotropy and spectral distortions in the CBR are limited by uncertainties in the knowledge of the galactic component. A program has been implemented for conducting an extended observational campaign to map the total sky brightness at several frequencies from 408 MHz to 1.5 GHz. The requirements and characteristics of the instruments and of the observing sites were presented.

I. Space missions in astronomy

43. The Hubble Space Telescope - Recent results and future plans: A brief history of the Hubble Space Telescope (HST), including the story of the spherical aberration in the primary mirror and the story of how this observatory has nevertheless become a premier research tool has been given. Recent results from HST have been shown, and plans for servicing the observatory at the end of 1993 were outlined.

44. Use of IUE data in advancing the knowledge of interacting binary stars. The use of IUE data in advancing our knowledge of the gaseous structure in interacting binaries was described. The existence of non-thermal sources of energy, their possible location and number, the velocity and temperature profiles of the gaseous structure and the effect of wind collision are some of the results that have come out of the UV study of those objects. The importance of the availability of IUE archive data was stressed.

45. Early results from the ROSAT mission. Since almost two and a half years the satellite observatory ROSAT is exploring the sky in the soft X-ray regime. The first All Sky Survey with an imaging X-ray telescope resulted in the detection of about 60 000 X-ray objects, an order of magnitude higher number than known before ROSAT. This large data base is now being used for detailed studies on individual objects, on selected samples from specific object classes and on general statistical source classification. Research topics range from investigations of stellar populations, of extended structures in the soft X-ray background like supernova remnants, studies of the properties of normal and active galaxies and of the hot gas in clusters of galaxies up to observations of the most distant quasars in the Universe. The All Sky Survey, performed in the early part of the mission, has in the meantime been complemented by appreciably deeper exposures on thousands of individual objects, measuring in detail their spatial, spectral and timing behaviour. Parallel to the X-ray research a high number of correlated studies have been arranged, specifically with the optical and the radio regimes, aiming for an understanding of the multi-wavelength appearance of the different astronomical objects.

46. ROSAT data handling. Data handling for the German X-ray satellite observatory ROSAT is based on the products originating from the initial processing of all data in the 4 ROSAT Scientific Data Centres in Germany (2), the United States of America and the United Kingdom. At these places a homogeneous calibration of all raw data is performed followed by a standard analysis of the source content in the observed sky images. This analysis results in a list of key parameters for all detected sources including the spectral and timing behaviour in case of stronger sources. Through the Standard Analysis the observer therefore obtains very early after the observation an overview on the quality and the outcome of the observation and can use this information as a starting point for a more detailed analysis. For this purpose the Data Centres provide ROSAT observers with interactive image analysis software systems allowing to perform many of the analysis tasks typically applied in this field of astronomy. With begin of November 1992 observational data enter the ROSAT Public Data Archive from where they can be requested by every interested scientist. As soon as a status is reached where most of the calibration and data evaluation problems have been understood also the results of the Standard Analysis processing will be transferred to the ROSAT Result Data Archive.

47. Activities of the Argentine Space Agency - The SAC-B project. A brief outline of the organization of space activities in Argentina since they started in 1960, as well as the present structure (as of 1991) and plans of the Argentine Space Agency was given. The aim and characteristics of the SAC-B scientific (astronomical) satellite project, its present status, and the instrumentation that will go onboard was described.

48. A balloon-borne imaging telescope for high-energy astrophysics. An imaging telescope for observations of Southern Hemisphere celestial sources in the energy band from 50 keV to 5 MeV onboard stratospheric balloons was described. The detector is a 41cm diameter, 5cm thick NaI(Tl) crystal coupled to 19 photomultipliers. The imaging capability is provided by a 19x19 element MURA-based mask mounted in an one-piece mask-antimask configuration. The angular resolution is of the order of 15 arcmin over a field of view of approximately 15 degrees. The platform, capable of pointing and stabilization with an accuracy of 5 arcmin in both azimuth and elevation, was also described.

49. The Cassini-Huygens mission. This mission will consist of a Saturn orbiter with a probe to be sent into the atmosphere of Titan. The Huygens probe is being built by ESA, the orbiter by NASA. Instruments and investigators from both Europe and the United States of America are involved in both components of the mission. Launch is scheduled for 1997, with arrival at Saturn in the year 2004. The orbiter payload consists of instruments for studying the planet, its rings, magnetosphere, and satellites, including a radar for sensing the surface of Titan. The probe will

study the atmosphere and surface of Titan throughout its 2.5 hour descent, and may make additional measurements if it survives its landing.

J. Education for space science

50. Mission to the Universe - Sharing space science through education. In 1992 and 1993, more than 20 astronomical observatories are, or will be, operating in space. This fleet of space observatories represents an extraordinary effort on the part of the human species to map the observable Universe across the spectrum. At the 2nd Pacific International Space Year Conference in Hawaii (Oct. 1991), an international group of astronomers dubbed this effort ''Mission to the Universe''. A brief overview of the ongoing effort was provided and the question of why, in a time of many pressing global problems, the nations of the world should invest resources in a space science effort like Mission to the Universe, was addressed. Six immediate benefits provided by Mission to the Universe were described: (i) New perspectives that help us to understand ourselves; (ii) Inspiration for education; (iii) A model of international cooperation; (iv) Development of technology; (v) Training of scientists and engineers; and (vi) A vision for the future to help humankind see the road ahead, if one solves the problems of the present. How Mission to the Universe might be used to inspire broader education, particularly in science, in developing nations was also addressed.

51. NASA's Initiative to Develop Education through Astronomy (IDEA). The Initiative to Develop Education through Astronomy represents a commitment by the NASA Astrophysics Division to promote excellence in education. IDEA is based on small augmentations of funding and modest additional effort by scientists, and is dedicated to making high-quality, accurate astronomical information available to educators and to the general public. IDEA's objectives include taking advantage of the universal appeal of astronomy to enhance mathematical, technological and scientific literacy, and increasing the representation of science of women and people of all cultures. Preliminary indications show image processing to be an effective and fun way to study the application of science and mathematics to "all world" applications, as represented by digital imagery. The use of image processing is also an innovative method for engaging students in inquiry and discovery learning. NASA has now developed an on-site teacher education programme for schools with the appropriate hardware. NASA has also developed a broad range of curricular materials built around image processing for a variety of science and mathematics content areas.

52. Activity-based astronomy instruction at low cost. The efficacy of activity-based instruction in the sciences has been well established in the literature. Unfortunately, activity-based instruction in astronomy is difficult due to limitation on

equipment and accessibility to a dark, night sky. Several low-cost activities that directly engage students using inexpensive materials and equipment have been described. Some of these materials have been developed at the Harvard-Smithsonian Centre for Astrophysics with assistance from the US National Science Foundation and others have been developed independently by researchers. A proposed Spanish-language version of some of these materials was discussed.

Annex II

PROGRAMME OF THE WORKSHOP

Venue: San José, Costa Rica

DATE/TIME	SUBJECT	SPEAKER
2 NOVEMBER 1992		
8 - 9 a.m.	Registration	
	Inauguration and opening ceremony	
9 - 9.10 a.m.	Welcome address	W. Fernandez
9.10 - 9.30 a.m.	Address by the Representative of the United Nations	N. Jasentuliyana
9.30 - 9.40 a.m.	Address by the Rector of the University of Costa Rica	C. Quesada
9.40 - 9.50 a.m.	Address by the Minister of Science and Technology of Costa Rica	O. Morales
	Chairperson: H.J. Haubold (UN)	
10.15 - 11.00 a.m.	European Space Agency Lecture: Archives and their relation to the development of fundamental scientific ideas	W. Wamsteker (ESA)
	Chairperson: A. Ocampo (USA)	
11 - 11.45 a.m.	The Planetary Society Lecture: Catastrophic impacts on Earth	C.R. Chapman (USA)
	Session: Origin of the solar system	
	Chairperson: C.-G. Faelthammar (Sweden)	
11.45 a.m. - 12.30 p.m.	Star formation	A. Poveda (Mexico)

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12.30 - 1.15 p.m.	Origin of the solar system	G. Wetherill (USA)

Session: Terrestrial interactions

Chairperson: K. Pope (USA)

2.45 - 3.30 p.m.	Magnetospheric plasma interactions	C.-G. Faelthammar (Sweden)
3.30 - 4.15 p.m.	Asteroids and comets	C.R. Chapman (USA)
4.30 - 5.15 p.m.	Meteorites	G. Wetherill (USA)

3 NOVEMBER 1992

Session: Terrestrial interactions (continuation)

Chairperson: L. Gonberoff (Chile)

9.00 - 9.45 a.m.	Magnetospheres and solar interaction I	M. Acuna (USA)
9.45 - 10.30 a.m.	Magnetospheres and solar interaction II	M. Acuna (USA)

Session: The terrestrial planets

Chairperson: G.A. Lemarchand (Argentina)

10.45 - 11.30 a.m.	Surface processes: Volcanism and tectonism	R. Lopes (USA)
11.30 a.m. - 12.15 p.m.	Surface processes on planets and satellites	R. Greeley (USA)
12.15 - 1.00 p.m.	The Moon	A. Ocampo (USA)
2.30 - 3.15 p.m.	The planet Mercury	C.R. Chapman (USA)
3.15 - 4.00 p.m.	Venus: Exploration via spacecraft	R. Greeley (USA)

4.15 - 5.00 p.m.	Mars: The red planet	A. Ocampo R. Greeley (USA)
5.00 - 5.45 p.m.	The special case of Io	R. Lopes (USA)

Special session: International basic space science activities

Chairperson: M. Acuna (USA)

6.00 - 6.45 p.m.	UN activities in basic space science	N. Jasentuliyana (UN)
6.45 - 7.30 p.m.	World Astronomy Days (WAD)	W. Wamsteker (ESA)

4 NOVEMBER 1992

Session: The Sun

Chairperson: M. Acuna (USA)

9 - 9.45 a.m.	Internal structure of the Sun	H.J. Haubold (UN) A.M. Mathai (Canada)
9.45 - 10.30 a.m.	The gallium solar neutrino experiment	R.v. Ammon (Germany)

Session: The Sun (continuation)

Chairperson: H.J. Haubold (UN)

10.45 - 11.30 a.m.	Applications and computational considerations of special functions to solar thermonuclear reaction rate integrals	W.J. Anderson A.M. Mathai (Canada) H.J. Haubold (UN)
11.30 a.m. - 12.15 p.m.	Solar neutrinos in relation to solar activity	D. Basu (West Indies)
12.15 - 1.00 p.m.	Changes in solar irradiance and atmospheric turbidity in Costa Rica during the total solar eclipse of 11 July 1991	W. Fernandez V. Castro J. Wright H. Hidalgo A. Saenz (Costa Rica)

2.30 - 3.15 p.m.	Variation of the geomagnetic field in Costa Rica during the total solar eclipse of 11 July 1991	G. Leandro J. Brenes W. Fernandez (Costa Rica)

Special session: Establishment of astronomical observatories in developing countries

Chairperson: H.J. Haubold (UN)

3.15 - 3.45 p.m.	National astronomical observatory in Peru - A proposal	M. Ishitsuka K. (Peru)
3.45 - 4.15 p.m.	Setting up a national astronomical observatory in Sri Lanka	N.C. Wickramasinghe (UK)
4.15 - 4.45 p.m.	Possibilities for astronomy in Peru	M.L. Aguilar (Peru)

5 NOVEMBER 1992

Session: The outer planets

Chairperson: R. Lopes (USA)

9 - 9.45 a.m.	Jupiter	G. Ballester (ESA)
9.45 - 10.10 a.m.	Saturn	T. Owen (USA)
10.10 - 10.30 a.m.	Uranus	T. Owen (USA)
10.45 - 11.30 a.m.	Neptune	C.R. Chapman (USA)
11.30 a.m. - 12.15 p.m.	Pluto, Triton, and Titan	T. Owen (USA)
12.15 - 1.00 p.m.	Modelling the Jovian planets by a simple analytical algorithm	J.F. Doorisn (USA)
2.30 - 3.15 p.m.	Bodies of ice	W. Smythe (USA)
3.15 - 4.00 p.m.	Surfaces of ice	W. Smythe (USA)
4.15 - 5.00 p.m.	Present understanding of the formation of giant planets	G. Wetherill (USA)

6 NOVEMBER 1992

Session: Life - A planetary phenomenon

Chairperson: Th. N. Gautier (USA)

9 - 9.45 a.m.	Comets, interstellar dust and the origin of life	N.C. Wickramasinghe (UK)
9.45 - 10.30 a.m.	Origin of terrestrial planet atmospheres	T. Owen (USA)
10.45 - 11.30 a.m.	The Earth as a planet	K. Pope (USA)
11.30 - 12.15 p.m.	Why visit Titan and Europa?	T. Owen (USA)
12.15 - 1.00 p.m.	Synthesis of organic compounds - A simulated Titanian atmosphere: An educational model	J.F. Doorish (USA)

Session: Life-A planetary phenomenon (continuation)

Chairperson: M. Schuch (Brazil)

2.30 - 3.15 p.m.	Life on Mars	C. McKay (USA)
3.15 - 4.00 p.m.	The origin of life in the solar system C. McKay	(USA)
4.15 - 5.00 p.m.	Detectability of extraterrestrial civilizations activities	G.A. Lemarchand (Argentina)
5.00 - 5.30 p.m.	Volcanoes on the Earth and planets	R. Lopes (USA)
5.30 - 6.00 p.m.	Introduction to the Poas field trip	E. Malavassi (Costa Rica)

7 NOVEMBER 1992

8 a.m. - 6 p.m. Field trip: Poas volcano

8 NOVEMBER 1992

Transfer to Bogota (Colombia)

PROGRAMME OF THE WORKSHOP

Venue: Bogota, Colombia

DATE/TIME	SUBJECT	SPEAKER
9 NOVEMBER 1992		
8 - 9 a.m.	Registration	
	Inauguration and opening ceremony	
9 - 9.10 a.m.	Welcome address	E. Posada
9.10 - 9.20 a.m.	United Nations address	P. Lala
9.20 - 9.30 a.m.	Address by the Rector of the University of the Andes	A. Infante
9.30 - 9.40 a.m.	Address by the Foreign Minister of Colombia	N.S. de Rubio
	Session: Dark matter and formation of structure in the Universe	
	Chairperson: A. Ocampo (USA)	
10.30 - 11.15 a.m.	International Space Year Lecture: Detection of astrophysical neutrinos	R.v. Ammon (Germany)
11.15 a.m. - noon	Structure and evolution of the Universe as a consequence of elementary particle properties I	J. Kleczek (Czechoslovakia)
noon - 12.45 p.m.	Structure and evolution of the Universe as a consequence of elementary particle properties II	J. Kleczek (Czechoslovakia)
	Session: Cosmic physics	
	Chairperson: H.J. Haubold (UN)	
2.30 - 3.15 p.m.	Astrometry in the Kerr field	J. Paez (Costa Rica) P. Frutos (Germany)

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3.15 - 4.00 p.m.	A remark on the one-photon-pair annihilation in strong magnetic fields	J. Bonatti J. Paez L. Semionova (Costa Rica)
4.15 - 5.00 p.m.	On the natural linewidth of absorption lines in strong stellar magnetic fields	E. Barbosa (Colombia) J. Bonatti (Costa Rica)

10 NOVEMBER 1992

Session: Cosmic Background Explorer (COBE): Observation and theory

Chairperson: J. Sahade (Argentina)

9 - 9.45 a.m.	COBE results and their cosmological implications	S. Torres (Colombia)
9.45 - 10.30 a.m.	Hydrodynamic stability and the formation of structure in the Universe	M.H. Ibanez (Venezuela)
10.45 - 11.30 a.m.	Evolution of perturbations after decoupling	R. Bautista (Colombia)
11.30 a.m. - 12.15 p.m.	Computational aspects of the gravitational instability problem for a multicomponent cosmological medium	A.M. Mathai (Canada) H.J. Haubold (UN)
12.15 - 1.00 p.m.	Mapping the galaxy: The Andes-Berkeley-INPE project	S. Torres (Colombia) G. de Amici G. Smooth (USA) T. Villela (Brazil)

Session: Cosmic Background Explorer (COBE): Observation and theory

Chairperson: M. Fernandez (Costa Rica)

2.30 - 3.15 p.m.	Non-linear thermal instabilities in the interstellar medium	A. Parravano (Venezuela)
3.15 - 4.00 p.m.	A balloon-borne imaging telescope for high-energy astrophysics	T. Villela (Brazil)
4.25 - 7.00 p.m.	Plenary session: Cooperation in basic space science in Latin America and the Caribbean	

Chairperson: W. Wamsteker (ESA)
Rapporteurs: S. Torres (Colombia)
M. Fernandez (Costa Rica)

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11 NOVEMBER 1992

Session: Space missions in astronomy

Chairperson: S. Torres (Colombia)

9 - 9.45 a.m.	The Hubble Space Telescope (HST): Recent results and future plans	J. Bennett (NASA)
9.45 - 10.30 a.m.	International Ultraviolet Explorer (IUE)	W. Wamsteker (ESA)
10.45 - 11.30 a.m.	Use of IUE data in advancing the knowledge of interacting binary stars	J. Sahade (Argentina)
11.30 a.m. - 12.15 p.m.	Early results from the ROSAT mission	H.-U. Zimmermann (Germany)
12.15 - 1.00 p.m.	ROSAT data handling	H.-U. Zimmermann (Germany)

Session: Space missions in astronomy (continuation)

Chairperson: T. Villela (Brazil)

2.30 - 3.15 p.m.	Activities of the Argentine Space Agency: The SAC-B project	J. Sahade (Argentina)
3.15 - 4 p.m.	Gamma ray astrophysics	N. Martinic (Bolivia)
4.15 - 5 p.m.	The problem of stellar membership in open clusters	A. Uribe E. Brieva (Colombia)
5 - 5.45 p.m.	The Radioastronomy Project - The National Agreement: CNPq/National Observatory and Federal University of Santa Maria	N. Schuch (Brazil)

12 NOVEMBER 1992

Session: Education for space science

Chairperson: A.M. Mathai (Canada)

9 - 9.45 a.m.	Mission to the Universe - Sharing space science through education	J. Bennett (NASA)
9.45 - 10.30 a.m.	NASA's Initiative to Develop Education through Astronomy (IDEA)	C. Morrow (NASA)
10.45 - 11.30 a.m.	Activity-based astronomy instruction at low cost	D. Hoff (USA)

11.30 a.m. - 1.00 p.m.	Working Group session
	Chairperson: W. Wamsteker (ESA)
2.30 - 4 p.m.	Working Group session (continued)
4.15 - 6 p.m.	Plenary session: Cooperation in basic space science in Latin America and the Caribbean
	Chairperson: J. Sahade (Argentina)

13 NOVEMBER 1992

9 - 10.30 a.m.	Plenary session: Cooperation in basic space science in Latin America and the Caribbean
	Chairperson: W. Wamsteker (ESA)
	Rapporteurs: H.J. Haubold (UN) S. Torres (Colombia)
10.45 - 11.30 a.m.	Closing session
	1. Report by the Chairperson of the plenary session
	2. Adoption of the report

Annex III

SELECTED REFERENCES

A. Salam: Ideals and Realities: Selected Essays of Abdus Salam (Ed. C.H. Lai), Second Edition, World Scientific Publishing Company Pte. Ltd., Singapore 1987.

A. Hamende, M.H.A. Hassan, J.L. Villaveces, and G. Violini (Eds.): Science in Latin America and the Caribbean and its Role in Regional Development. Vol.I and II, Academia Colombiana de Ciencias Exactas, Fisicas y Naturales; Centro Internacional de Fisica; Instituto Colombiano para del Desarrollo de la Ciencia y la Tecnologia-Colciencias; Third World Academy of Sciences; 1992.

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